# Unit V
# Building a Prototype Using Off-the-Shelf Components

The quickest way to realize a physical prototype is to build the prototype using off-the-shelf components.

The more off-the-shelf components that can be purchased and used, the
quicker the prototype can be realized.

# HOW TO DECIDE WHAT TO PURCHASE

This section will help answer the following questions:

- How to decide what to purchase?
- What to consider in order to decide what is needed?
- How to come up with a bill of materials so that the system is complete?
- Why and how to prioritize a list of items to purchase?

**To decide what needs to be purchased for a product prototype, one can follow the product development process steps**

1. Define the requirements
2. Produce a conceptual design
3. Produce a final design
4. Manufacture the machine or system

**For example,**

- when conceptually designing an aircraft, sometimes it is known whether an engine will need to be purchased as the engine is a major component.
- However, one may decide to purchase a particular joining device at the last minute of prototype fabrication.
- What this says is that the decision could be made at any stage, but often it is made in steps 2 and 3.

**The analysis of part requirements should include many aspects:**

- Functionality
- Working environment, temperature
- Volume, size, weight
- Safety
- Cost
- Schedule
- Make/buy, etc.

# PURCHASING DECISION FOR A PROTOTYPE

- Make/buy decision is used to decide whether a part should be made in-house or should be purchased.

- Most companies are dependent on others as part suppliers.

- Most companies design and make only a portion of what makes up their products, buying the rest from a complex multilink chain of suppliers.

The reasons for buying instead of making a component may be due to one or more of the following facts:

1. The company cannot make the component or easily acquire such a capability and must seek a supplier
2. The supplier has a lower cost, and/or faster availability
3. The supplier's version of the item is better for any number of possible reasons

On the other hand, the reasons for making a component in-house could be due to one or both of the following facts:

1. The item is crucial to the product's performance, or the skill in producing it has been judged critical to the company's technical competence.
2. In-house has lower cost or faster capability.

The make/buy decision may also be impacted by whether the product is designed
to have modular architecture or integral architecture.

A product with a modular architecture has components that can be mixed and matched due to standardization of function to some degree and standardization of interfaces to an extreme degree.

For Example
Home stereo equipment has a modular architecture
As one can choose speakers from one company,
A CD player from another,
A tape deck from a third,
All the parts from the different manufacturers will assemble together into a system.

A product with an integral architecture,
on the other hand, is not made up of off-the-shelf parts, but rather comprises a set of components and subsystems designed to fit with each other.

For example
Airplanes are an example.
The product must be developed as a system and the components and subsystems are defined by a design process exerted from the top–down

After the needs and requirements have been defined, a conceptual design of the system or machine can be developed.

- This should create an overview of what the system may look like.
- The overview may be more of a list of specifications for each component within the machine or system than an actual picture.

specifications, changes or trade-offs may be made before the final design and manufacturing stages.

These changes or trade-offs may include:

- Changing power sources
- Increasing or decreasing power requirements
- Changing material selection
- Changing controller systems
- Modifying operator interface requirements
- Modification of ambient operating environment

# WHAT TO PURCHASE?

No matter what kind of product, to decide what kind of components are needed,
the functional efficiency technique.

The first step is to start with a list of the derived functions for a new product.
The second step is to find the relationships among the functions by arranging the functions into a logical orderly fashion, and finding the sub-functions and its related units.

The physical objects that cannot be made in-house are the components that will need to be purchased.

One needs to investigate the details of the prototype, such as

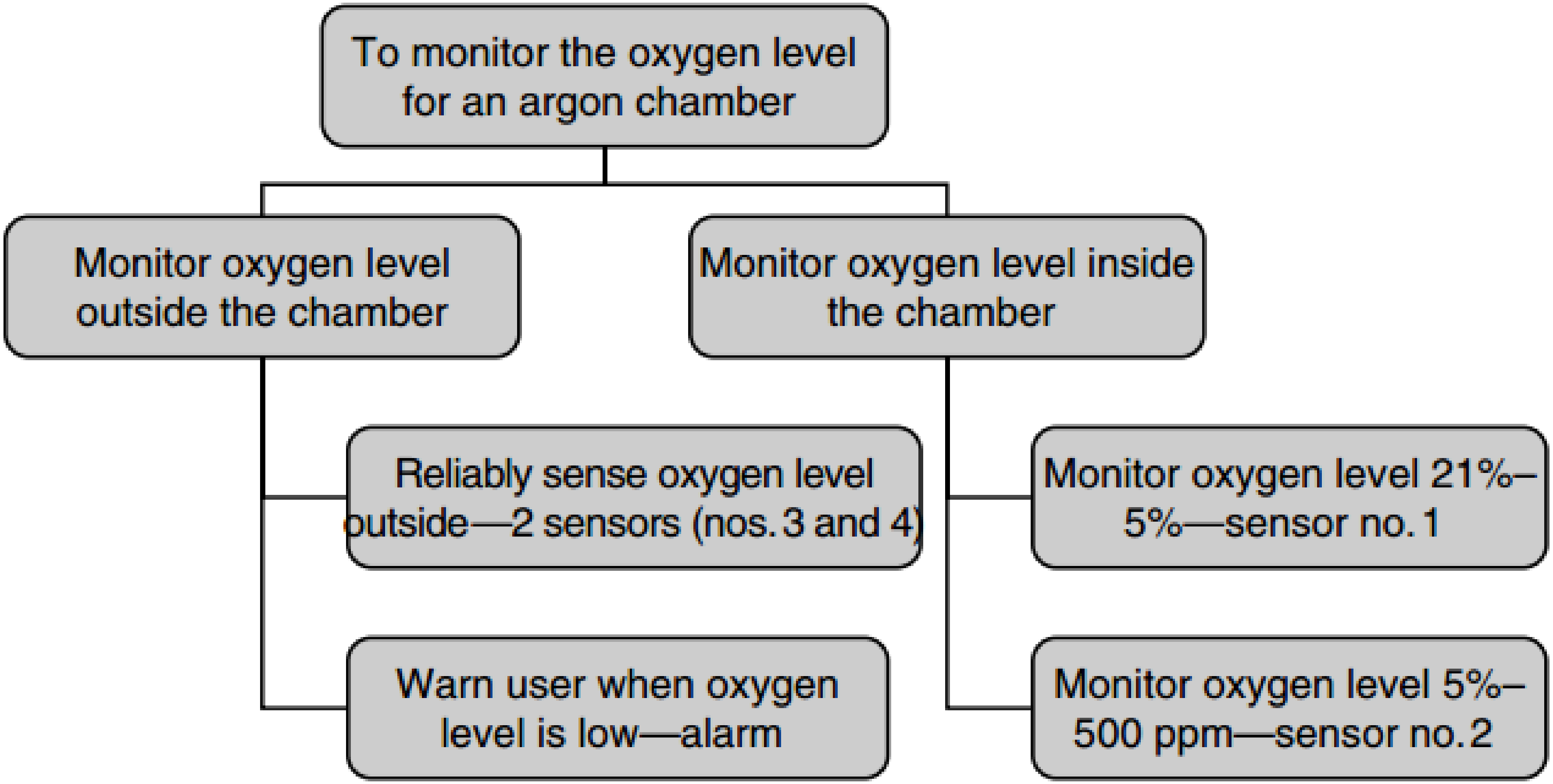
- Cost
- Functionality
- Other important points of the prototype or product before making or buying.

# SENSOR PURCHASING

This case study includes an oxygen-detecting system in a newly developed chamber. Assume that one does not have much knowledge about sensors and does not have the capability to make a sensor, but needs to purchase the system.

1. **Objective**: To design, purchase, and integrate a sensor in an argon chamber to detect the oxygen level during the entire manufacturing process when the chamber air is replaced with the argon gas.
2. **Goal**: In addition to maintaining less than 500 ppm (parts per million) oxygen level for processing, it is necessary to maintain a safe environment for the operator outside of the chamber.
3. **Constraints/conditions**:
   a. The air contains about 21% oxygen and 78% nitrogen.
   b. The argon-filling process will take several hours to bring the oxygen level from 21% to 500 ppm.
   c. Monitoring the oxygen level inside the chamber during these hours is necessary.
   d. The chamber will occupy about half of the volume of the room, and thus an oxygen sensor and an alarm system are needed outside the chamber to make sure that the operator can operate in a safe condition.

4. **Sensor system design and specifications**:
   e. **Overall**: There should be three sensors: A first sensor to detect the oxygen level in the chamber, a second sensor to detect the level of oxygen outside the chamber, if possible, a third sensor to act as a backup to the second sensor for the safety of the people inside the lab, but outside the chamber.
   f. **Inside sensors**: The inside sensor should measure the oxygen level in ppm. If possible, it should have the capability to measure from 21% to 500 ppm.
   g. **Outside sensors**: The two outside sensors should measure the oxygen level in percentage of oxygen. They should be independent of the system control or system PLC.
   h. **Life**: Oxygen sensors normally have a certain life span as it involves a chemical reaction, and thus at certain time intervals some chemical components should be replaced. The sensor should have a considerably long life.
   i. **Integration**: The sensors will be integrated in a chamber controlled PLC, and thus should be compact, easy to handle and mount.
   j. **Cost**: The sensor should fit in the estimated budget.

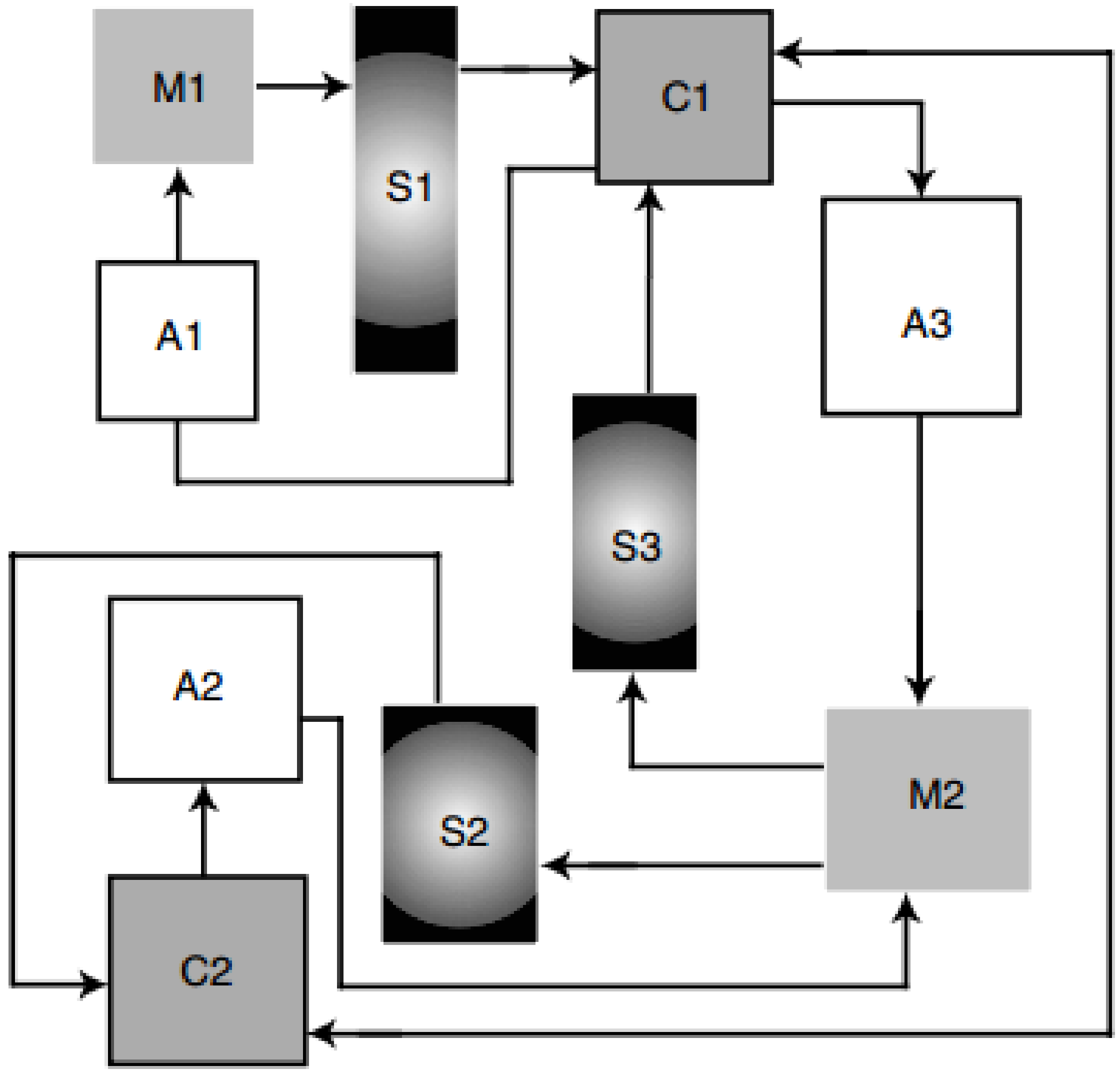



The sensor design result based on the functional efficiency technique.

## Sensors Selected

| Product | Company/Specs | Unit | Unit Price | | Comments |
|---|---|---|---|---|---|
| Series 1000 oxygen analyzer | Alpha-omega; accuracy: ±1% of full scale | 1 | \$1744 |  | Oxygen sensor to be used inside the chamber for use in the range 21%–1% |
| Series 3000 trace oxygen analyzer | Alpha-omega: accuracy: ±1% of full scale | 1 | \$3018 |  | Sensor to be used inside the chamber in the range 5%–500 ppm or 500–50 ppm |
| Fixed oxygen monitor | Analox: two alarm set points at 19.5% and 18% | 2 | \$595 | <br>The Analox 1 main sensor and remote repeater unit | Sensors to be used outside the chamber to warn the operator when the oxygen level is low. One extra sensor is used as a backup |

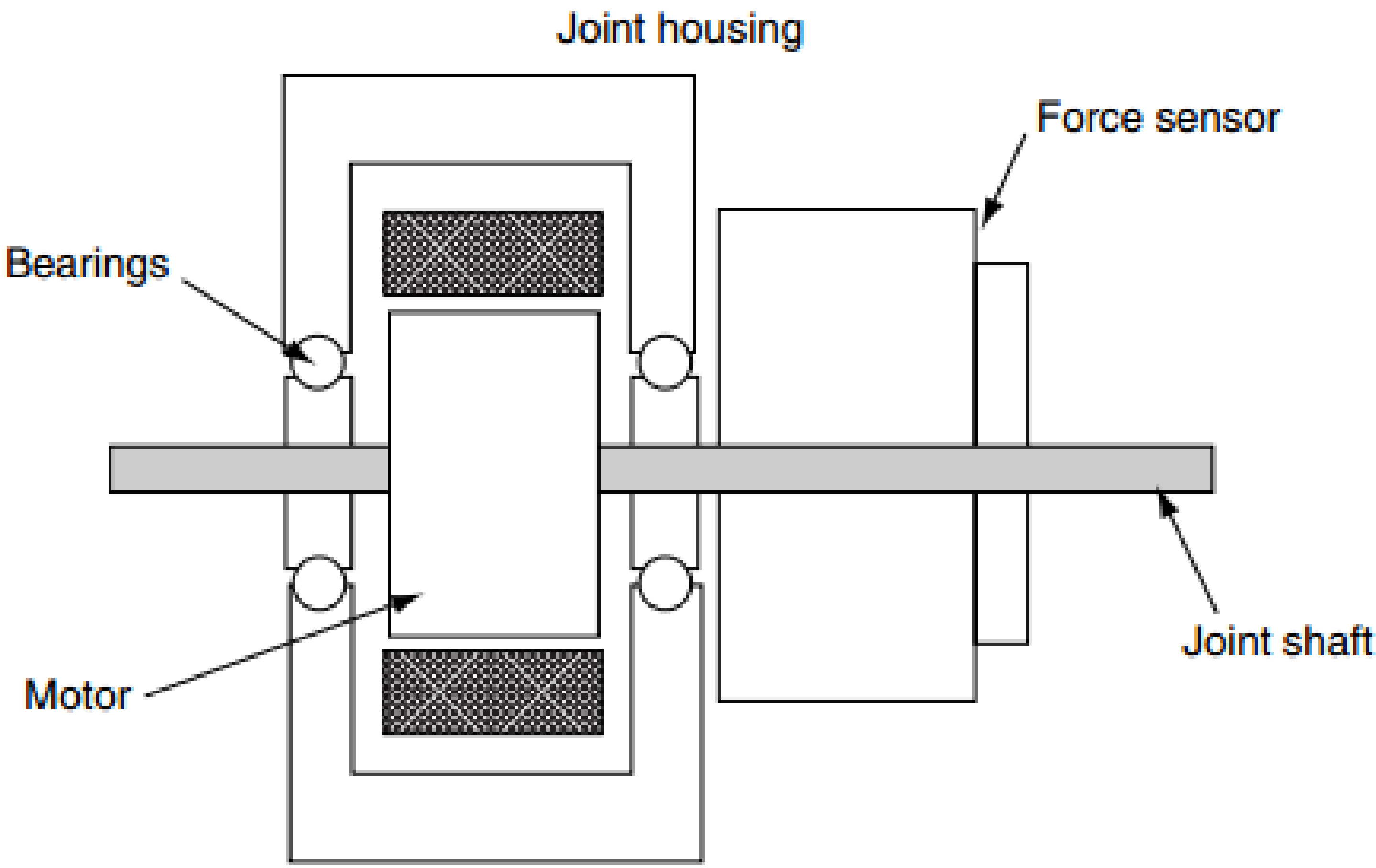
| Originator | Receiver | Signal |
|---|---|---|
| A1 | M1 | Force |
| M1 | S1 | Speed |
| S1 | C1 | Voltage |
| C1 | A1 | Voltage |
| C1 | A3 | Voltage |
| A3 | M2 | Force |
| M2 | S3 | Position |
| S3 | C1 | Voltage |
| C1 | C2 | Voltage |
| C2 | C1 | Voltage |
| C2 | A2 | Voltage |
| A2 | M2 | Force |
| M2 | S2 | Limit |
| S2 | C2 | Voltage |



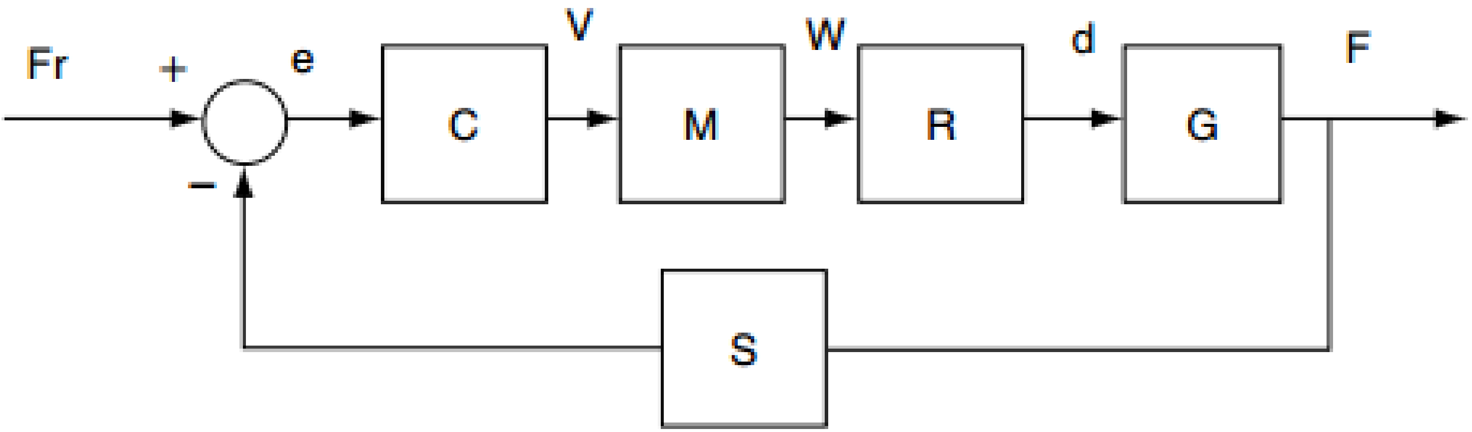

A Actuator
C Computer (Control Station)

S Sensor
M Mechanism

# SELECTING AND PURCHASING SENSORS FOR A FRICTION STIR WELDING ROBOT




Schematic diagram of the robot motion joint and the force sensor.




| Originator | Receiver | Signal |
|---|---|---|
| C (controller) | M (motor) | $V$: voltage |
| M (motor) | R (robot joint) | $W$: rotation speed |
| R (robot joint) | G (friction stir device) | $d$: plunge depth |
| G (friction stir process) | S (force sensor) | $F$: force |

Signal flow diagram of the sensor.

# DEVELOPMENT OF A TEMPERATURE CONTROLLER FOR CPU FANS

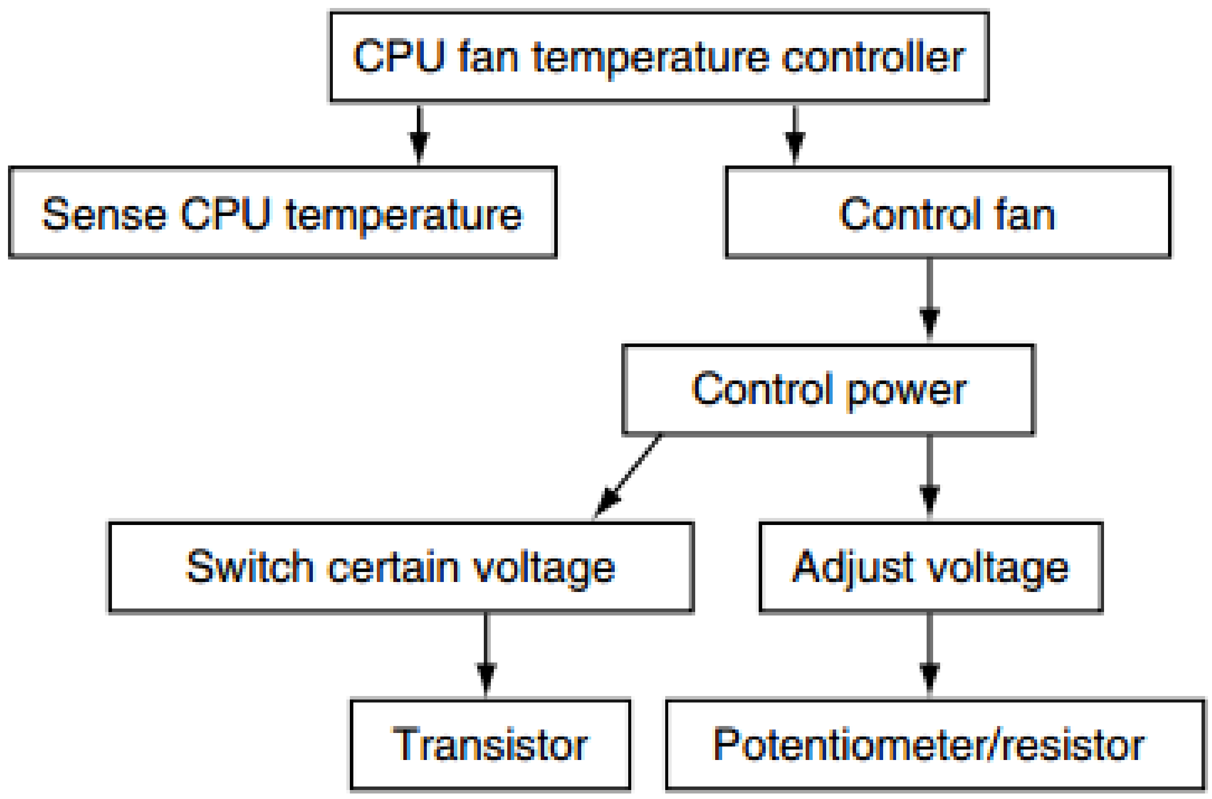
The fans are always spinning at maximum speed—no matter if the CPU is running at full load or is idle.
No matter if the outside temperature is 30 C or 16 C.
The user cannot adjust the temperature.

## 1. Requirements

Based on the problems discussed above, the requirements of this temperature controller are as follows:

.Temperature setting can be adjusted by the user
. Fans are switched off if the temperature is low enough
. Several fans can be controlled with just one sensor and temperature control
.Low cost

# 2. Function analysis




The functional diagram of the temperature controller for a CPU fan.

## 3. Planning

Objective:

- To build a temperature controller that costs less than $20.
- The user can adjust the temperature at which fans should be turned-on.
- Several fans can share one sensor and temperature control.

Purchasing components

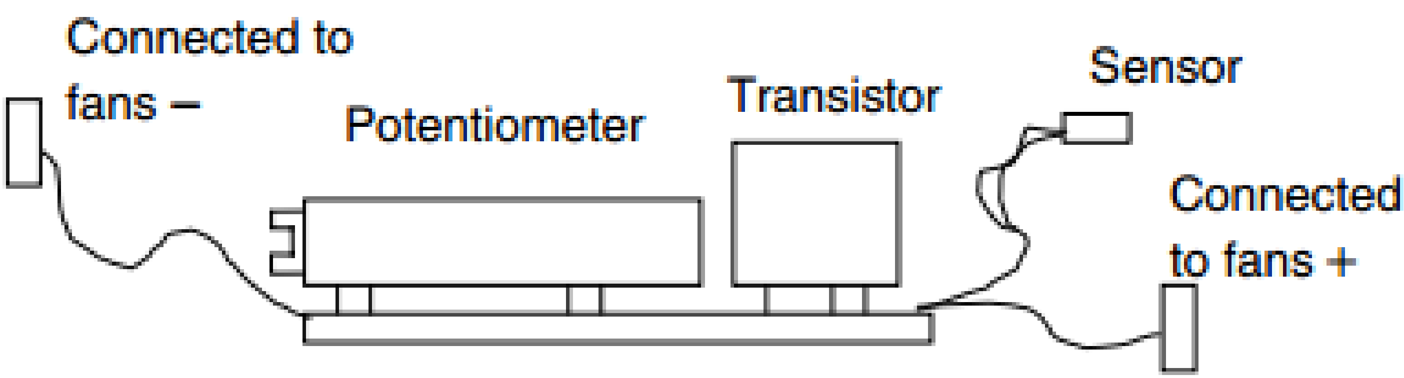
. Power transistor

. Temperature sensor

. Potentiometer or resistor

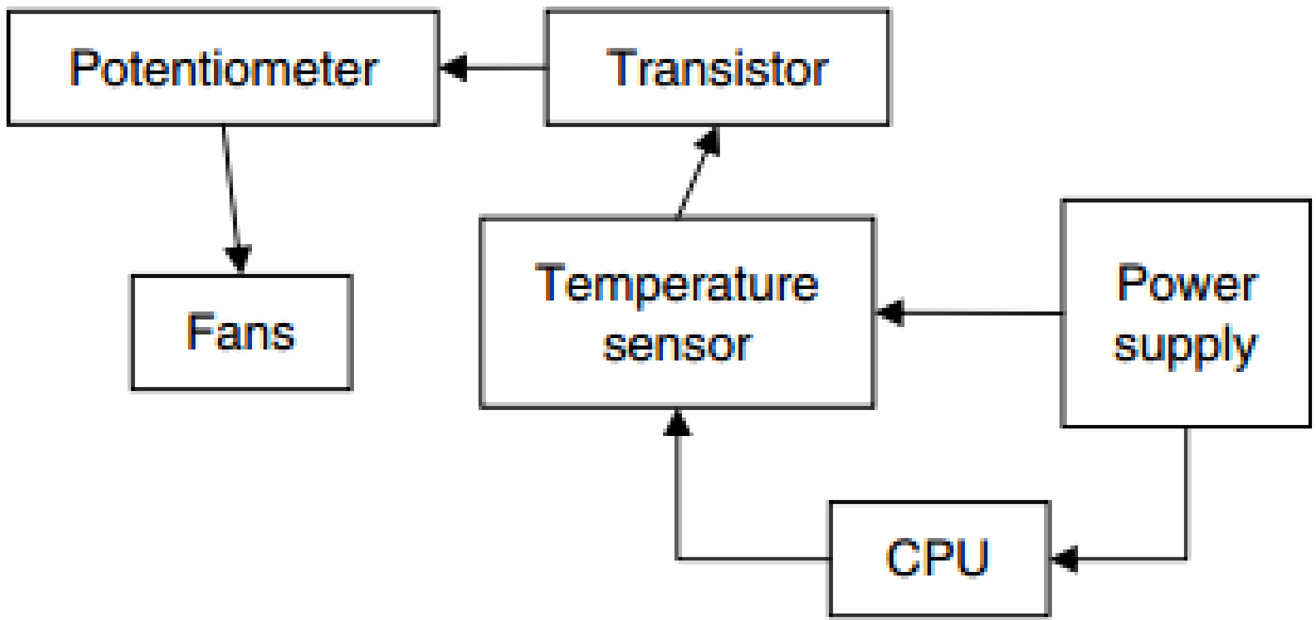
. Heat-contractible tubing

. A little printed circuit board (PCB) (for mounting such parts)




Assembly of the system components.

# 5. Signal flow diagram




| Originator | Receiver | Signal |
| --- | --- | --- |
| CPU | Sensor | Temperature |
| Sensor | Transistor | Voltage |
| Transistor | Potentiometer | Voltage |
| Potentiometer | Fans | Voltage |
| Power | CPU | Voltage |
| Power | Sensor | Voltage |

6. Prioritize the precision of the system
   The precision from high to low is
   sensor > transistor > potentiometer
7. Main components selection
   The main selection criteria are
   - The size should be small
   - Inexpensive (less than \$5)
   - Resistance should be at least 10 kΩ
8. Final choice: NTC Thermistor (from www.jameco.com) at \$1.59
   - Operating temperature range: –30°C ~ +130°C
   - Thermal dissipation factor (@ 25°C): 6.5 mW/°C
   - Resistance value allowable difference: 10%
   - Resistance (@ 25°C): 10 kΩ
   - B Constant 25°C/50°C (10%): 4100
   - Temperature coefficient (at 25°C): –4.6 (%/°C)

HOW TO FIND THE CATALOGS THAT GAVE THE NEEDED COMPONENTS

**TABLE 7.2**
**Some Commonly Used Web Sites for Off-the-Shelf Components**

| Company | Web Site |
|---|---|
| FastenerNet | http://www.fastenernet.com/ |
| Carr Lane | http://www.carrlane.com/ |
| Grainger | http://www.grainger.com/Grainger/wwg/start.shtml. |
| iCrank | http://icrank.com/cgi-bin/pageman/pageout.cgi?path = /directory.htm&t=1 |
| McMaster-Carr | http://www.mcmaster.com/ |
| Information Handling Services | http://www.ihs.com/catalogxpress/ |
| Global Spec | http://www.globalspec.com/ |
| Thomas Register | http://www.thomasnet.com/ |
| Wiha Quality Tools | http://www.wihatools.com/distlink2.htm |
| Part Solutions | http://www4.cadenas.de/wunschkatalog.asp?sid=2 |
| Omega | http://www.omega.com/ |
| Fisher Scientific | https://www1.fishersci.com/index.jsp |

- In the current internet age, finding information and products is easier than ever before.
- Simply look in the local yellow pages or go online to www.yellowpages.com and look under industrial equipment, industrial supplies, manufacturing part distributors, machine tools, or other related topics to find local distributors.
- A catalog from one of the large component suppliers, such as Grainger or McMaster-Carr.

# EVALUATING COMPANIES AND PRODUCTS

To narrow the vendor company and product list, the designers need to make some judgments.

The designers will have to weigh several factors:

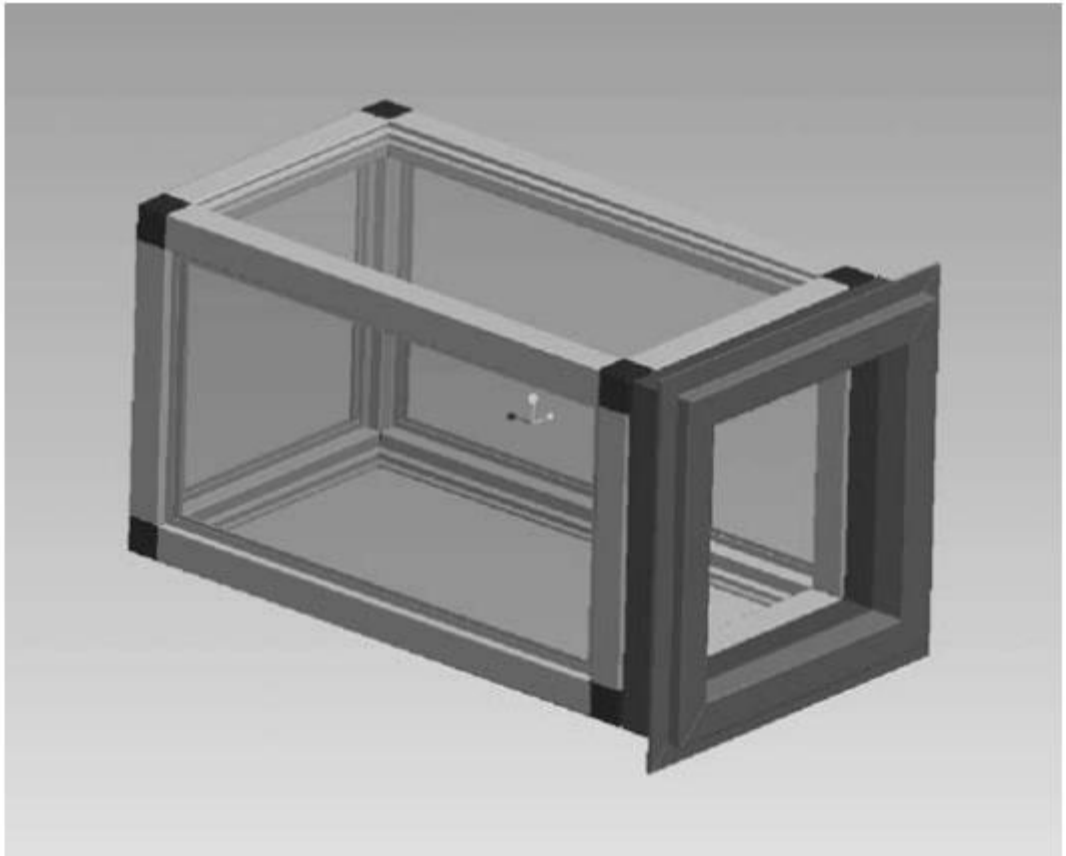
- **Cost**—the cost to the life cycle of the product.
- **Quality**—is balanced with cost but is important to the final product.
- **Technical support**—which is helpful both during the design while the product is being integrated into the system and during use when it requires repair or maintenance.
- **Features**—more features up front may mean the designers will have to do less integration into the automation system.
- **All the requirements**—power usage, noise, space, etc.

## Component selection

- Ordering components can sometimes be just as difficult as trying to figure out which components are to be used in the first place.
- Some of the components needed are back ordered or are no longer available.
- If time is not overly important then a back order is not a problem, but an item which is no longer available may be a concern.

# DESIGNING AND IMPLEMENTATION OF A TRANSFER CHAMBER

- The objective of this project is to design and implement a removable transfer chamber for an argon chamber.
- A transfer chamber can transfer the specimens from outside to inside or inside to outside with a minimal amount of gas loss.
- The transfer chamber is designed to be removable so that it allows movement in front of the chamber to be easier and reduces the risk of a collision with the transfer chamber thus causing a leak in the main chamber that can possibly harm someone.
- The total budget is estimated to be at $1000.



Option to make a box transfer chamber.

Either make a chamber or purchase a chamber.

To purchase a transfer chamber, one option was to purchase an inflatable chamber or to purchase a box style transfer chamber.

The options of making a chamber are building a box style transfer chamber as shown in Figure, or building a tube style transfer chamber.

## Estimated Cost for Made Box Transfer Chamber

| Description | Price ($) | Qty | Total ($) |
|---|---|---|---|
| Polycarbonate (box) 24 × 24 × 0.25 | 27.51 | 1 | 27.51 |
| Polycarbonate (hatch) 12 × 12 × 0.375 | 13.90 | 1 | 13.90 |
| Aluminum extruded channel (box no. 7) 8 in. | 29.62 | 1 | 29.62 |
| Aluminum extruded channel (box no. 7) 4 in. | 15.40 | 1 | 15.40 |
| Aluminum extruded channel (chamber no. 2) 4 in. | 15.40 | 1 | 15.40 |
| 3-Way corner pieces | 8.95 | 8 | 71.60 |
| Aluminum 6063-T5 square tubing (6 ft) 0.0625 wall | 8.33 | 3 | 24.99 |
| Lift-off hinges (left 2 in. width × 2 in. leaf height) | 1.96 | 2 | 3.92 |
| Ball valve for purge (3⁄8 pipe size) female/female | 4.38 | 2 | 8.76 |
| Barbed × pipe fitting (3⁄8 pipe size) | 6.88 | 1 | 6.88 |
| Aluminum 6063 T-52 angle bracket (1.5 in. × 1.5 in. × 0.0625) 8 in. | 10.00 | 1 | 10.00 |
| 90° pipe bend (male × male) | 3.67 | 2 | 7.34 |
| 3⁄8 pipe lock nut | 0.81 | 5 | 4.05 |
| Sealing materials for transfer chamber | 1.58 | 7 | 11.06 |
| Tubing | 4.00 | 1 | 4.00 |
| Latches | 8.00 | 1 | 8.00 |
| Screws | 4.00 | 1 | 4.00 |
| Internal hinges | 8.00 | 1 | 8.00 |
| Internal latches | 8.00 | 1 | 8.00 |
| Drawer slides | 5.95 | 1 | 5.95 |
| | | Total | 288.38 |

## House of Quality for Comparing the Ideas for Absolute Importance

**5 = Meets requirement/best**
**1 = Fails requirement/worst**

| | | Type | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Purchase Box Style Chamber | | Self-Made PVC Pipe | | Purchase Inflatable Chamber | | Self-Made Box Style Chamber | |
| **Requirement** | **Weight** | **Raw** | **Weighted** | **Raw** | **Weighted** | **Raw** | **Weighted** | **Raw** | **Weighted** |
| Part size | 0.15 | 5 | 0.75 | 5 | 0.75 | 5 | 0.75 | 5 | 0.75 |
| Weight capacity | 0.15 | 5 | 0.75 | 5 | 0.75 | 5 | 0.75 | 5 | 0.75 |
| Usable volume | 0.1 | 4 | 0.4 | 2 | 0.2 | 3 | 0.3 | 4 | 0.4 |
| Storage | 0.1 | 1 | 0.1 | 3 | 0.3 | 5 | 0.5 | 3 | 0.3 |
| Ease of use | 0.1 | 4 | 0.4 | 4 | 0.4 | 4 | 0.4 | 4 | 0.4 |
| Customizable | 0.05 | 1 | 0.05 | 3 | 0.15 | 1 | 0.05 | 4 | 0.2 |
| Price | 0.2 | 1 | 0.2 | 2 | 0.4 | 1 | 0.2 | 4 | 0.8 |
| Ease of manufacturing | 0.1 | 5 | 0.5 | 3 | 0.3 | 5 | 0.5 | 2 | 0.2 |
| Additional accessories | 0.05 | 4 | 0.2 | 4 | 0.2 | 3 | 0.15 | 3 | 0.15 |
| Total | 1 | 30 | 3.35 | 31 | 3.45 | 32 | 3.6 | 34 | 3.95 |

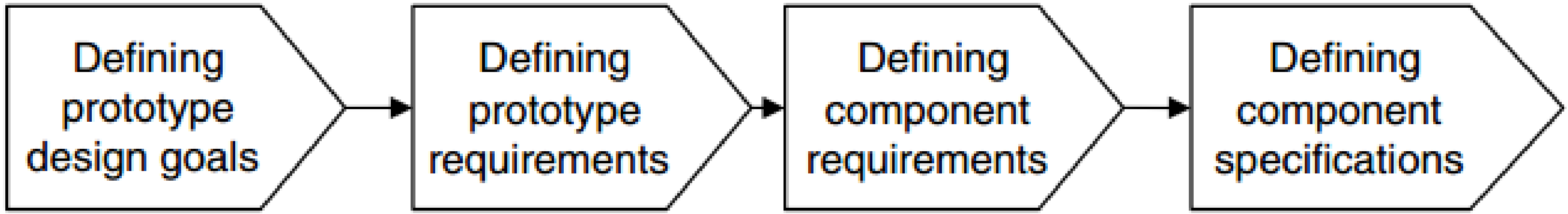
## HOW TO ENSURE THAT THE PURCHASED COMPONENTS WILL WORK TOGETHER

This section will help answer the following questions:

- How to make sure that the items purchased can be used in the project?
- What are the tools available to ensure proper assembly of components?
- In addition to the assembly issue, are there other factors to be considered?

To make sure that the ordered components will work, a lot of homework needs to be done before purchasing, including prototype assembly planning, using a CAD system for virtual simulation, tolerance analysis, and effective communication with the components' vendor. Functional compatibility and geometric compatibility are the keys.

In general, it is important to read the specifications in the component catalog carefully when purchasing the items.
Make sure that the device, wiring hose, and connectors will all fit together before the purchase.




Defining prototype components specifications.

The key specifications when defining prototype design goals may include :
performance, environment,
service life, cost, shipping, quantity, aesthetics, materials, standards and specifications, quality and reliability, safety, etc.

# Benefits of CAD prototype

- Allows for quick design–evaluate–modify iterations, reducing cost and time
- Improves accuracy and quality
- Less or no need to produce a physical prototype
- Capable of simulation and virtual prototyping, including computational fluid dynamics, finite element analysis, motion analysis/kinetics, human interaction
- Measures tolerances and clearances
- Defines multiple configurations
- Determines volume and weight
- Parts can be readily produced from the prototype model

Functional compatibility and geometric compatibility

Geometric compatibility, two steps need to be carried out: prototype assembly planning and tolerance analysis.

TOLERANCE ANALYSIS

- How to conduct tolerance analysis so that parts can fit together?
- What are the commonly used mechanical fits? Are there any standards on these?
- What are the definitions of these mechanical fits? What are their applications?
- What is a clearance fit? What is an interference fit? What is a transition fit?
- How to assign tolerances to a specific fit?

# TOLERANCE ANALYSIS

- It is impossible to make parts to an exact size.
- The tolerance required will depend on the function of the part and the particular feature being dimensioned.
- Therefore, the range of permissible sizes, or tolerance, must be specified for all dimensions on a drawing.
- A successful design creates a product assembly which contains parts that fit together well.

Tolerance analysis can be used to increase understanding of part function,
To discover and resolve problems on paper rather than in prototype or production
To make intelligent design decisions.

In the expression $1 \pm 0.1$, the limits are the maximum and minimum sizes. In this case, they are 1.1 and 0.9. The tolerance is the permissible amount of variation, or

$$1.1 - 0.9 = 0.2 \text{ or } 1 \pm 0.1.$$

# Mechanical FIT

- Clearance fit is when the largest shaft is always smaller than the smallest hole.
- Interference fit is when the sizes of the shaft are always larger than the sizes of the hole.
- Transition fit is when the largest shaft is larger than the largest hole.

## ANSI Fits Standard

**ANSI Recommended Allowances and Tolerances**

| Class of Fit | Description | Clearance | Interference | Hole Tolerance | Shaft Tolerance |
|---|---|---|---|---|---|
| 1 | Loose | $0.0025^3\sqrt{(d^2)}$ | | $+0.0025^3\sqrt{(d)}$ | $-0.0025^3\sqrt{(d)}$ |
| 2 | Free | $0.0014^3\sqrt{(d^2)}$ | | $+0.0013^3\sqrt{(d)}$ | $-0.0013^3\sqrt{(d)}$ |
| 3 | Medium | $0.0009^3\sqrt{(d^2)}$ | | $+0.0008^3\sqrt{(d)}$ | $-0.0008^3\sqrt{(d)}$ |
| 4 | Snug | 0 | | $+0.0006^3\sqrt{(d)}$ | $-0.0004^3\sqrt{(d)}$ |
| 5 | Wringing | | 0 | $+0.0006^3\sqrt{(d)}$ | $+0.0004^3\sqrt{(d)}$ |
| 6 | Tight | | $0.0025d$ | $+0.0006^3\sqrt{(d)}$ | $+0.0006^3\sqrt{(d)}$ |
| 7 | Medium force | | $0.0005d$ | $+0.0006^3\sqrt{(d)}$ | $+0.0006^3\sqrt{(d)}$ |
| 8 | Shrink | | $0.001d$ | $+0.0006^3\sqrt{(d)}$ | $+0.0006^3\sqrt{(d)}$ |

. For example, if the nominal size of a fit is ½ in., then the minimum size of the hole in the system is 0.500 in. The calculations are summarized below:

$$\text{Clearance} = \text{Hole} - \text{Shaft}$$

$$\text{Clearance}_{\text{max}} = \text{Hole}_{\text{max}} - \text{Shaft}_{\text{min}}$$

$$\text{Clearance}_{\text{min}} = \text{Hole}_{\text{min}} - \text{Shaft}_{\text{max}}$$

$$\text{Allowance} = \text{Clearance}_{\text{min}} = \text{Hole}_{\text{min}} - \text{Shaft}_{\text{max}}$$

If both clearance$_{\text{max}}$ and clearance$_{\text{min}}$ are greater than zero, it is a clearance fit.
If both clearance$_{\text{max}}$ and clearance$_{\text{min}}$ are smaller than zero, it is an interference fit.
If clearance$_{\text{max}}$ is greater than zero and clearance$_{\text{min}}$ is smaller than zero, it is a transition fit.

# Upper and lower deviation



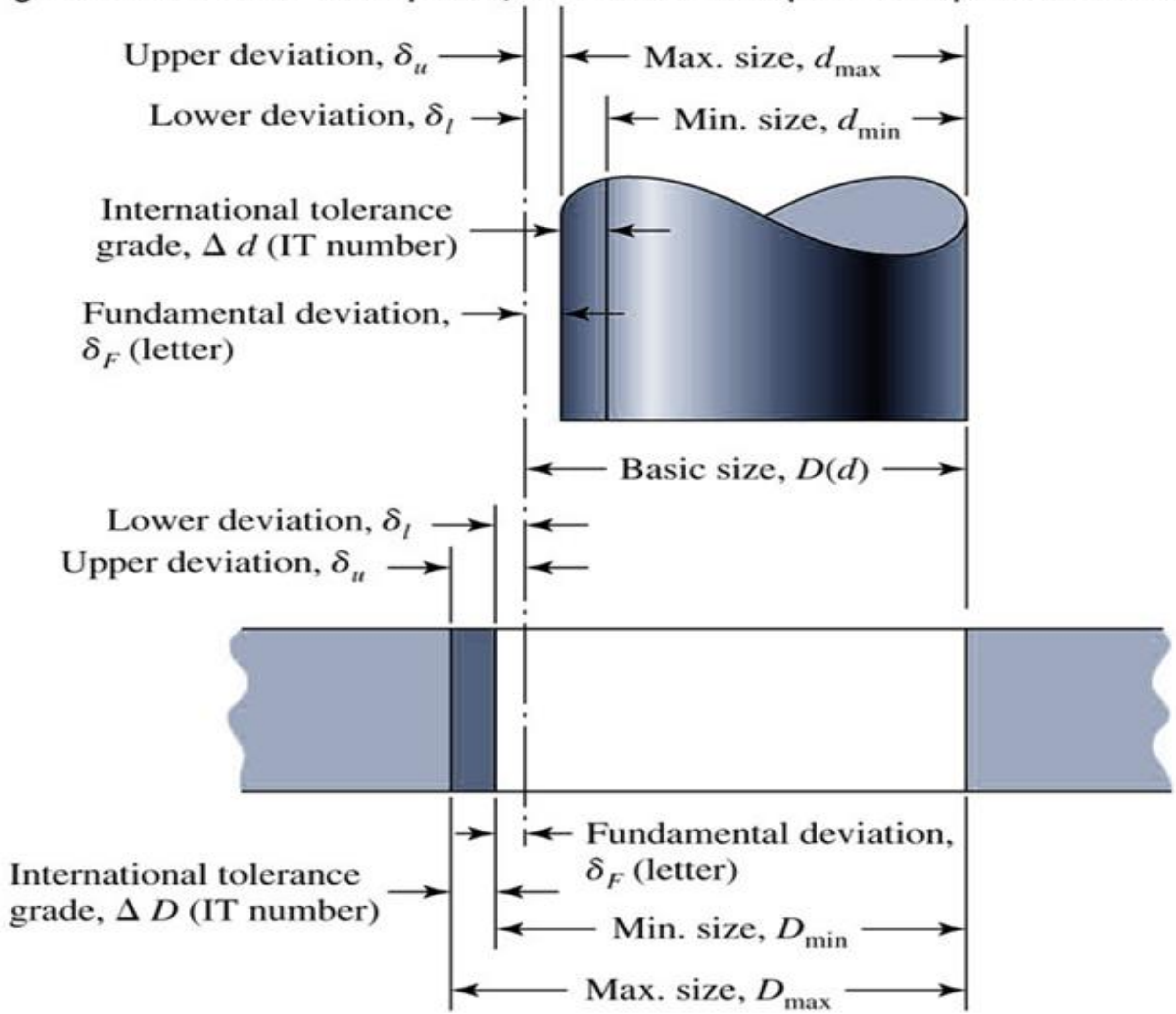


**TABLE 7.10**
**Some Preferred ISO Example Limits and Fits Using the Hole Basis System**

| Description | Hole | Shaft |
|---|---|---|
| Loose running | H11 | c11 |
| Free running | H9 | d9 |
| Loose running | H11 | c11 |
| Easy running—good quality easy to do | H8 | f8 |
| Sliding | H7 | g6 |
| Close clearance—spigots and locations | H8 | f7 |
| Location/clearance | H7 | h6 |
| Location—slight interference | H7 | k6 |
| Location/transition | H7 | n6 |
| Location/interference—press fit which can be separated | H7 | p6 |
| Medium drive | H7 | s6 |
| Force | H7 | u6 |

| Feature | Specification |
|---|---|
| Hole designation | 22 H11 |
| Total tolerance | 130 µm |
| Upper deviation | 130 µm |
| Lower deviation | 0 µm |
| Limits of size (LMC/MMC) | 22.130 ~ 22.000 mm |
| Shaft designation | 22 g9 |
| Total tolerance | 52 µm |
| Upper deviation | −7 µm |
| Lower deviation | −59 µm |
| Limits of size (LMC/MMC) | 21.993 ~ 21.941 mm |

Comment: This fit has a maximum clearance of 189 µm and a minimum clearance of 7 µm.

**Advantages:-** 1.Time for the manufacture of components is reduced
2.The cost of pieces is reduced.
3. Spare parts can be quickly made available.

**Disadvantages:-** 1. Special purpose machines are necessary.
2.Jigs and Fixtures are needed.
3. Gauges are to be used instead of conventional precision instruments.
4. Initial expenditure will be very high.

TOLERANCE STACK ANALYSIS

This section will help answer the following questions:

- What are tolerance stacks?
- Why is tolerance stack analysis important?
- How does one conduct tolerance stack analysis?

To make sure that two parts can be assembled properly, in addition to the CAD assembly drawing, tolerance analysis is needed.

Tolerance stack is a calculation which determines the maximum and minimum distance between two features on a part or in an assembly.

Stacks help us ensure good product design and reduce product costs.

Stacks can be linear or radial.

Radial stacks often involve diametrical dimensions

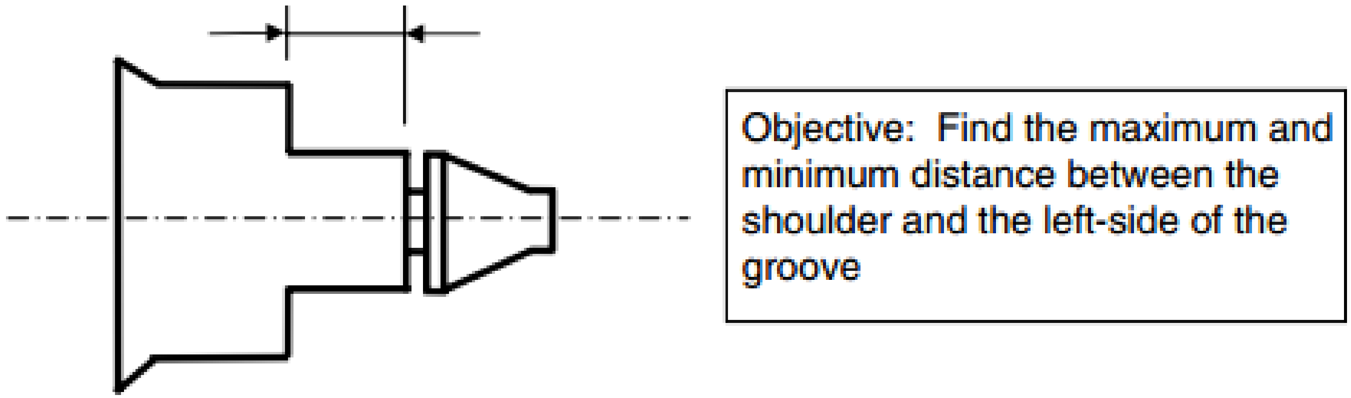
# Basic stack steps are:

**Identify the problem:** Identify the stack objective, list the conditions under which the stack is being calculated, and label the start point, end point, and direction of the stack.

**Choose the desired answer:** Write down the design goal before solving the problem.

**Identify the stack path:** A stack path is a series or chain of distances (part dimensions) from the start point of the stack to the end point of the stack.

**Perform the math:** Transfer the distances onto the stack form, add each column of numbers, check the subtotals




An example to define stack objective.

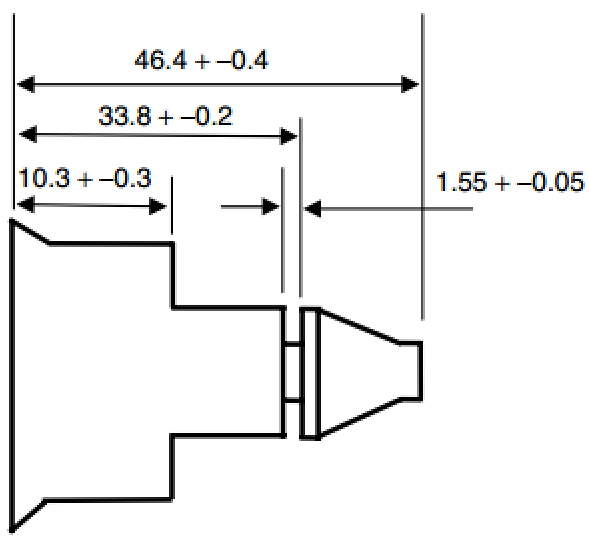
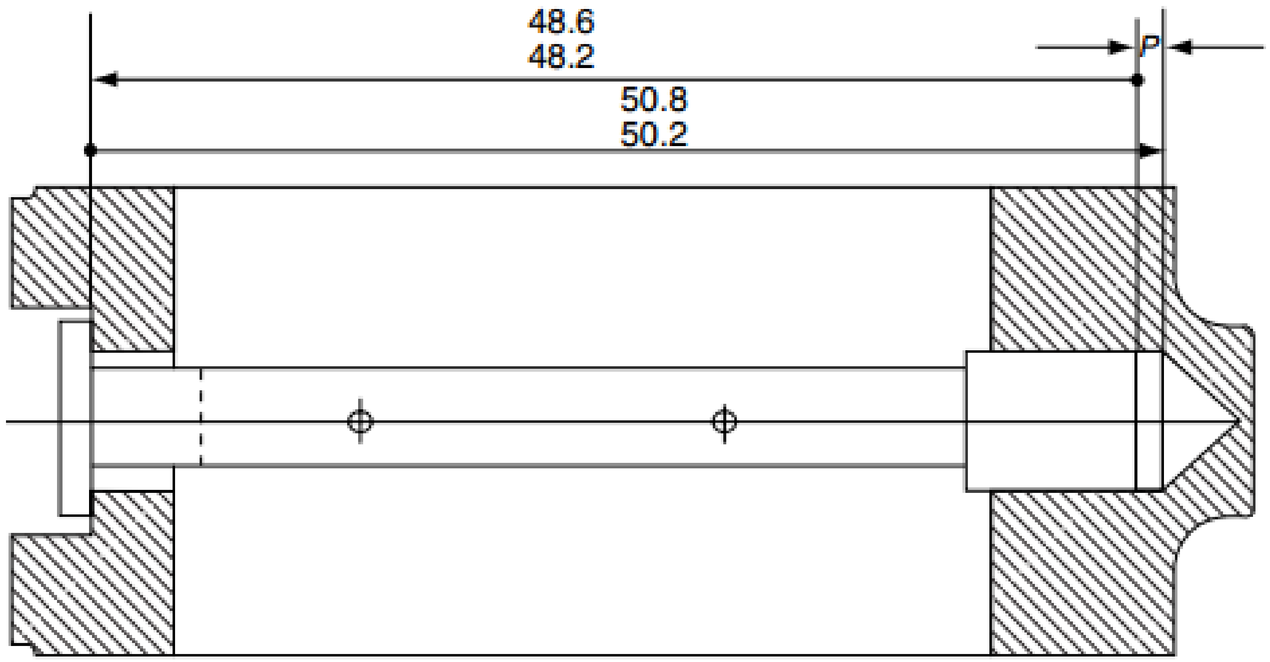
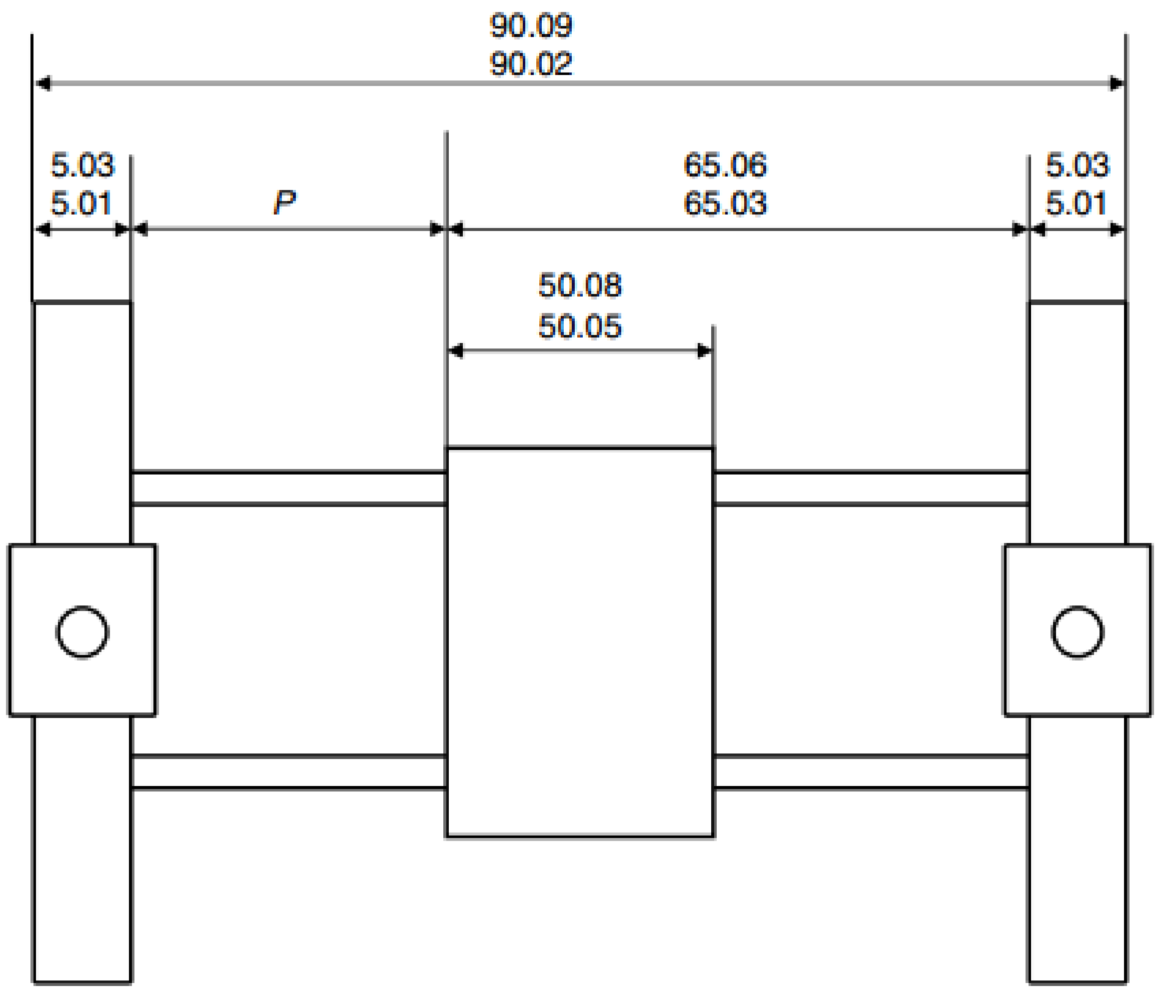



**FIGURE 7.24** A series or chain of distances (part dimensions) from the start point of the stack to the end point of the stack.




To find the maximum and minimum value of $P$.




To find the maximum and minimum value of $P$.

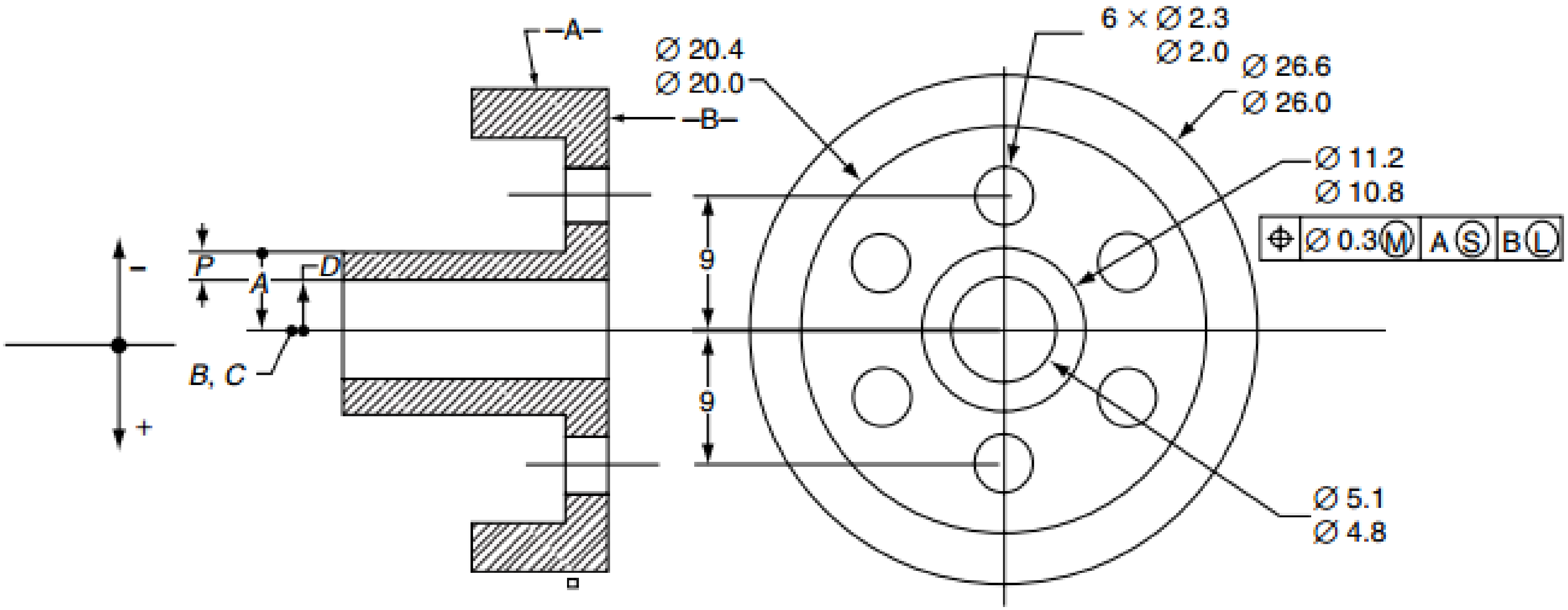



**FIGURE 7.33** To find the maximum and minimum value of $P$.

# ASSEMBLY STACKS

This section will help answer the following questions:

- How to analyze the tolerance stacks of an assembly?
- What is the procedure of assigning tolerances for components in an assembly?

When two or more parts are assembled together, assembly stack analysis is needed in order to determine whether these parts can be successfully put together.

In assembly stack problems, generally there are two situations, assembly with clearances, and without clearances between assembly components.

**To find assembly tacks with clearances, one can follow the four basic stack steps in the previous section with one additional action:**

1. **Identify the problem:**
    - Identify the stack objective,
    - list the conditions under which the stack is being calculated,
    - label the start point, end point,
    - Direction of the stack.

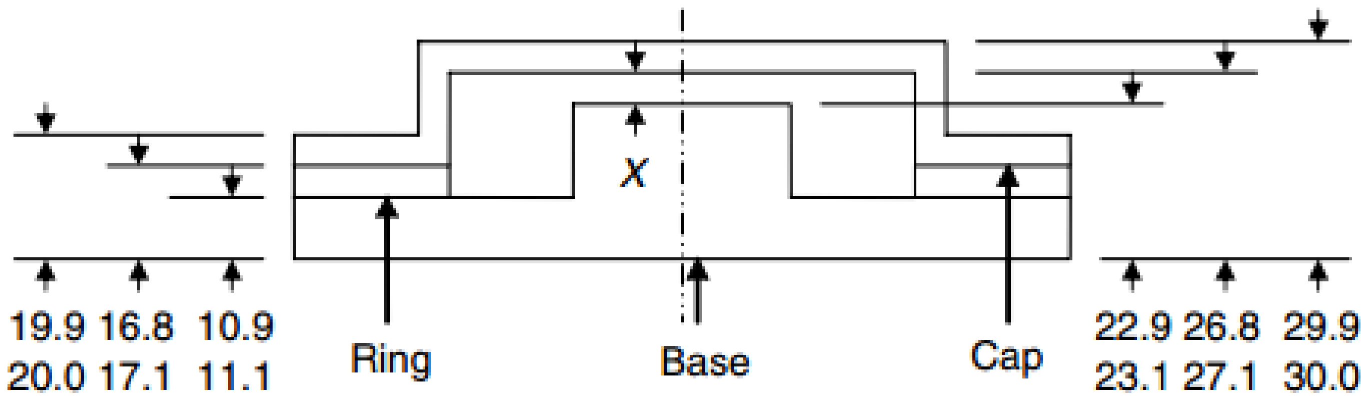
2. **Choose the desired answer:** Write down the design goal. ‘‘What is the extreme maximum (or minimum) answer that would be acceptable and allow the product to function as intended?’’

3 **Identify the stack path:**

A stack path is a series or chain of distances (part dimensions) from the start point of the stack to the end point of the stack.

4. **Perform the math:**

Transfer the distances onto the stack form, add each column of numbers, check the subtotals, and evaluate the answer.




Ring, base, and cap assembly (cross-section view).

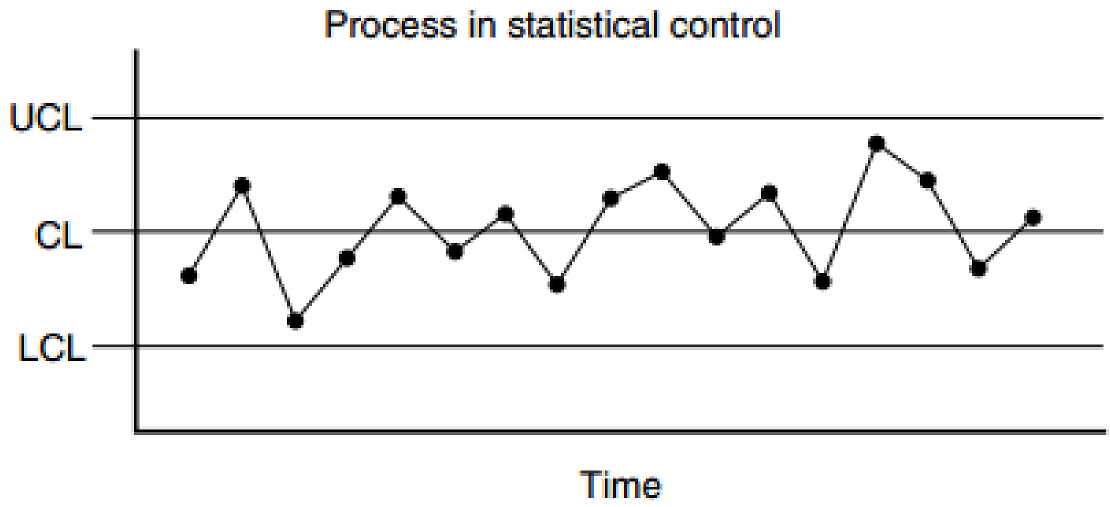
# PROCESS CAPABILITY

This section will help answer the following questions:

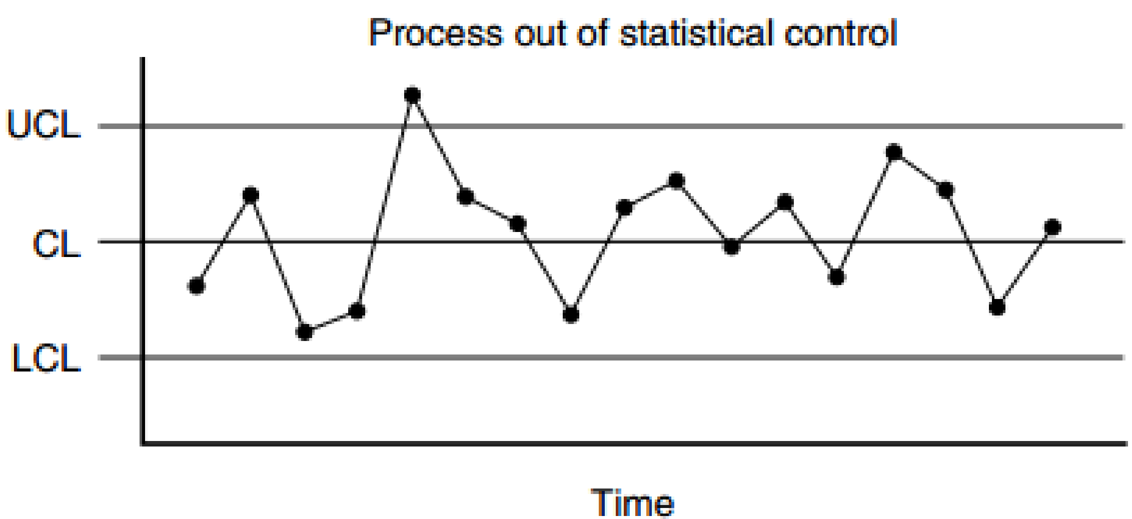
- What is process capability?
- Why is process capability important in tolerance analysis?
- What are capability indices? How can they be used to represent a process capability?

- Process capability describes the capability of specific manufacturing equipment or processes to meet certain tolerance requirements.
- Therefore, process capability can be used to help determine which machine(s) or process(es) to use to manufacture a part or a set of parts.

- Process capability compares the output of an in-control process to the specification limits by using capability indices.
- As a capable process is one where almost all the measurements fall inside the specification limits.
- The process capability index uses both the process variability and the process specifications to determine whether the process is capable.




Process in statistical control.




Process out of statistical control.

# STATISTICAL TOLERANCE ANALYSIS

- As the cost of production increases geometrically for incremental tightening of tolerances, sometimes it is not possible to achieve economically.

- In addition to the worst case tolerance analysis, there is another alternative, i.e., statistical tolerance analysis.

- The statistical tolerance analysis would not change the resulting tolerance sum of the tolerance chain.
- A statistical tolerance analysis is conducted to specify appropriate tolerances about the nominal values established in parameter design to achieve a balance between setting wide tolerances to facilitate manufacture and minimizing tolerances to optimize product performance.