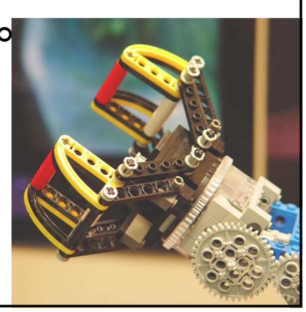
ROBOT END EFFECTORS

1

End Effectors

- The special tooling for a robot that enables it to perform a specific task
- Two types:
  - Grippers – to grasp and manipulate objects (e.g., parts) during work cycle
  - Tools – to perform a process, e.g., spo
    spray painting



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Grippers and Tools

3

Grippers

- Grippers are end effectors used to grasp and hold objects

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Classification of Grippers

- Mechanical
- Magnetic
- Vacuum
- Adhesive
- Miscellaneous Devices

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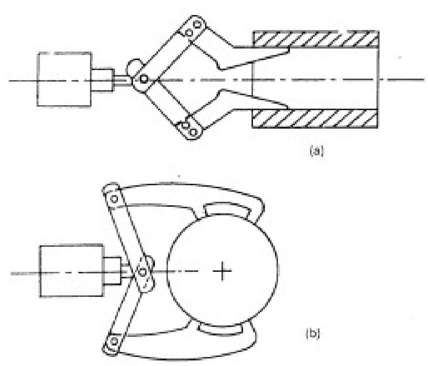
External/Internal Grippers



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Mechanical Gripper

- A mechanical gripper is an end-effector that uses mechanical fingers actuated by a mechanism to grip an object.
- The fingers are the appendages of the gripper that actually makes contact with the object. The fingers are either attached to the mechanism or are an integral part of the mechanism.
- The use of replaceable fingers allows for wear and interchangeability.
- Differents sets of fingers for use with the same gripper mechanism can be designed to accommodate different parts models.

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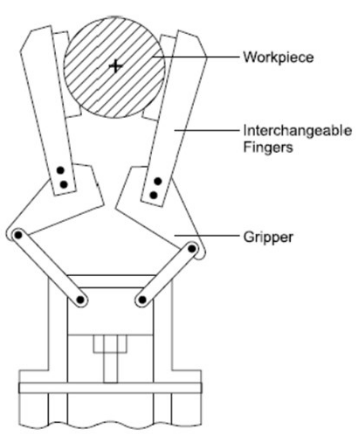
Mechanical Gripper



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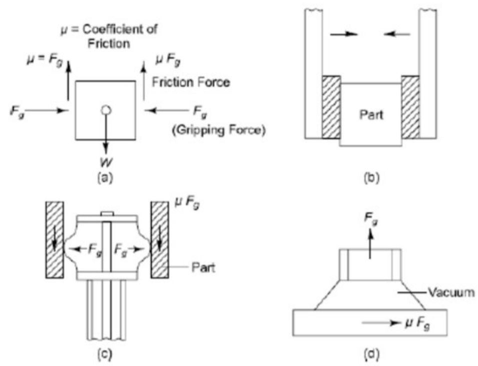
Mechanical Gripper Analysis

$$F_g = \frac{mg \sin\theta}{\mu n}$$

where m = mass, kg
g = acceleration due to gravity, m/s^2
μ = coefficient of friction
θ = angle subtended with the horizontal
n = number of pairs of contact surfaces



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1. The angle, θ that the gripping surface subtends to the horizontal.
2. The coefficient of friction, μ between the gripping surface and the load surface.

The gripping force that must be applied is

$$F_g = \frac{mg\sin\theta}{\mu n}$$

where

m = mass, kg

g = acceleration due to gravity, m/s^2

μ = coefficient of friction

θ = angle subtended with the horizontal

n = number of pairs of contact surfaces

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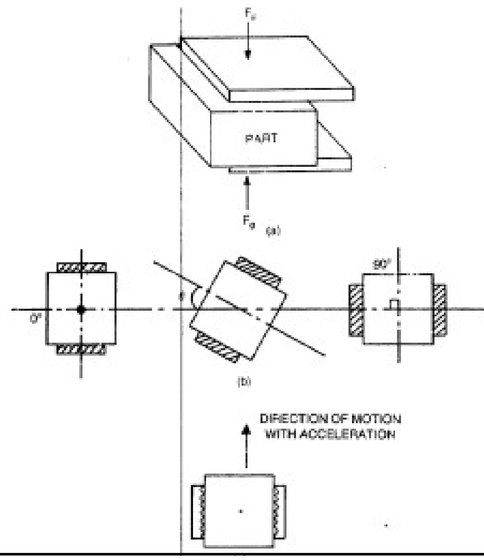
Mechanical Gripper Analysis



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Example 4.2 A 5 kg rectangular block is gripped in the middle and lifted vertically at a velocity 1 m/s. If it accelerates to this velocity at 27.5 m/s^2 and the coefficient of friction between the gripping pads and the block is 0.48, calculate the minimum force that would prevent slippage.

Considering the free body diagram (Fig. 4.21)

$$2\,\mu\,F_g - mg = ma \qquad \text{[considering two fingers]}$$

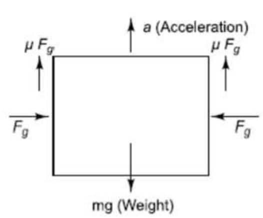
where *a* is the acceleration upward or,

$$F_g = \frac{m(a+g)}{2\mu}$$

$$= \frac{5(27.5+9.8)}{2\times 0.48}$$

$$= 194.1\ \text{N}$$

Figure 4.21 *Figure of example problem 4.2*



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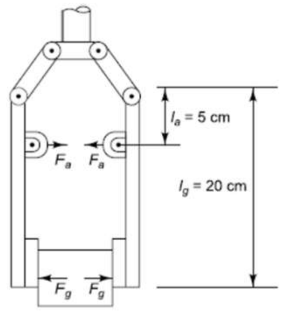

Taking moments of the forces on one arm and summing them to zero, we get,

$$F_g L_g = F_a l_a$$

$$\text{or,} \quad F_a = \frac{F_g l_g}{l_a} = \frac{20 \times 20}{5} = 80 \text{ kgf}$$

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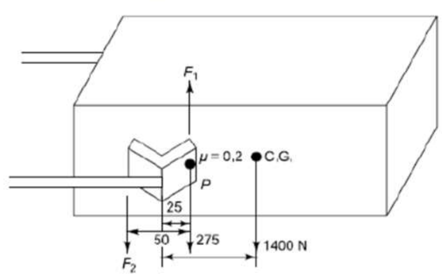
Example 4.4 A block of weight having 1400 N is to be gripped as shown in Fig. 4.23. Find the clamping force assuming a safety factor of 2. Assume coefficient of friction $\mu = 0.2$. The centre of gripping does not coincide with the centre of gravity.

Figure 4.23 Figure of example problem 4.4



Assuming acceleration $a \uparrow$ upward,

Resolving vertical forces $1400 + 2F_2 = 2F_1 - \frac{W_a}{g}$

Resolving moments about P, $50\, F_2 = (1400 \times 250)/2$

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$$F_2 = \frac{1400 \times 250}{50 \times 2} = 3500 \text{ N}$$

$$F_1 = 5600 \text{ N [assume } a = 2 \text{ g]}$$

$$\text{Clamping force} = \frac{(F_1 + F_2) \times \text{safety factor}}{\mu}$$

$$= \frac{9100 \times 2}{0.2} \text{N}$$

$$= 91000 \text{ N}$$

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a. Calculate the vacuum cup area for grasping a plate weighing 200 pounds if the number of vacuum cups on the end-effector is 4. Pressure differential is 10 psi.

[Use no. of cups × cup area × ($p_{\text{atmos press}} - p_{\text{inside press}}$) = weight of plate]

b. If frictional coefficient μ is 0.4 and safety factor for the above problem is 2, what is area of the vacuum cup?

$$A = \frac{W}{\mu(\delta p)FS}$$

$$\mu = 0.4$$
$$FS = 2$$
$$p = 10 \text{ psi}$$
$$W = 200 \text{ lbs}$$

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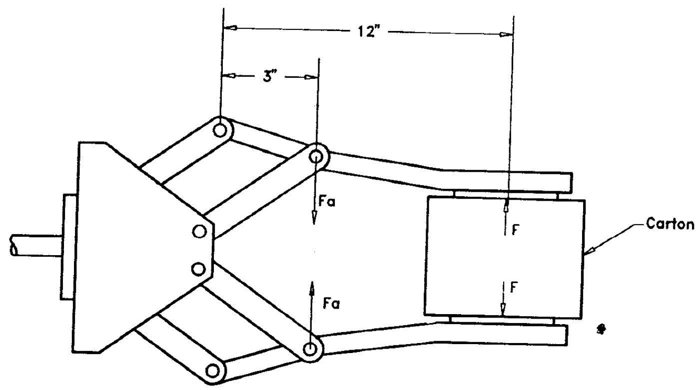
Gripper Mechanism Analysis



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Mechanical Gripper Analysis

An angular motion gripper is used for holding the cardboard carton, as shown in Figure 5.3.1. The gripper force, calculated in Example 5.1, is 60 pounds. The gripper is to be activated by a piston device to apply an actuating force *Fa*. Determine the piston device force *Fa* to close the gripper.

Solution

The analysis would require that the moments about the pivot arms be summed and made equal to zero.

$$\Sigma M = 0$$

$$FL - FaLa = 0$$

$$(60\text{lb})(12") - (\text{Fa})(3") = 0$$

$$Fa = \frac{720}{3} = 240 \text{ lb}$$

The piston device would have to provide an actuating force of 240 pounds to close the gripper with a force against the carton of 60 pounds.

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Mechanical Gripper Analysis

Figure 5.3.2 shows the linkage mechanism and dimensions of a gripper used to handle a work part for a machining operation. The gripper force is determined to be 25 pounds. Determine the actuating force Fa applied to the plunger.

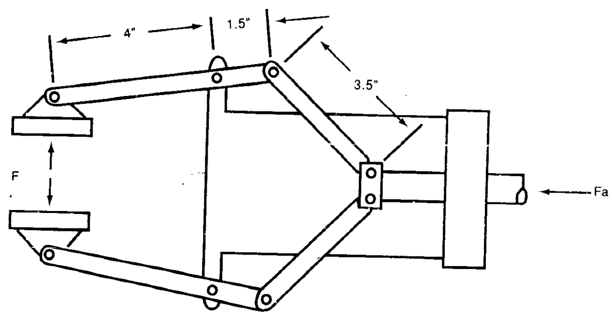

Figure 5.3.2 Gripper used in Example 5.4

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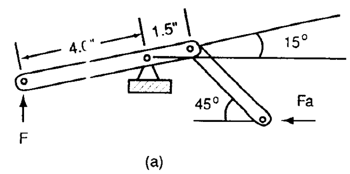

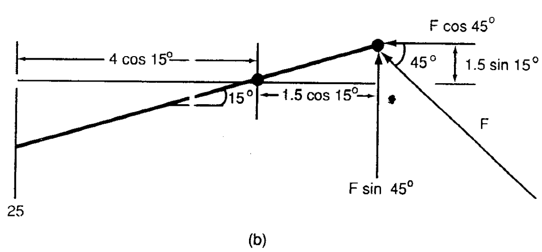

$$25(4\cos 15^\circ) = F\sin 45^\circ(1.5\cos 15^\circ) + F\cos 45^\circ(1.5\sin 15^\circ)$$

$$96.6 = (1.0246 + 0.2745)F = 1.2991F$$

$$F = 74.4 \text{ lb}$$

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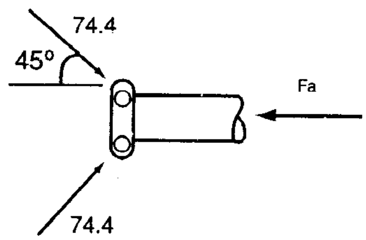

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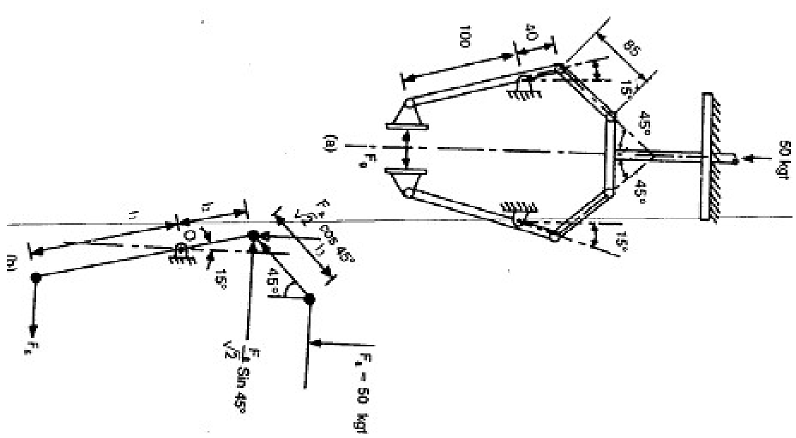

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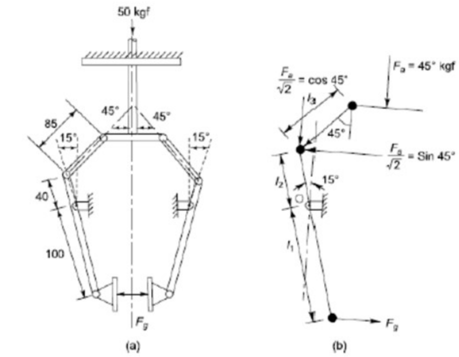

$$F_g \times l_1 \cos 15^\circ = \left(\frac{F_a}{\sqrt{2}}\sin 45^\circ\right)\cdot l_2 \cos 15^\circ + \left(\frac{F_a}{\sqrt{2}}\cos 45^\circ\right)\cdot l_2 \sin 15^\circ$$

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4.18 A vacuum pump to be used is to maintain a pressure differential of 3 N/cm^2 (i.e. $p_{atm} - p_{res}$) compared to atmospheric pressure. The gripper is used to lift 400 mm × 900 mm plate having a net weight of 300 N. Assuming two suction cups engaged for lifting the weight, determine the diameter of the suction cups. Assume a factor of safety of 1.4.

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Mechanical Grippers

- Linkage Actuation
- Gear and Rack Actuation
- Cam Actuation

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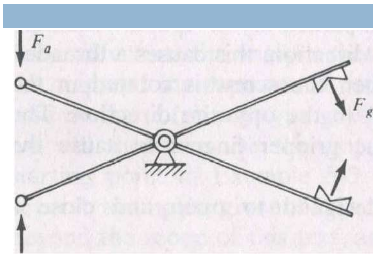
Linkage Actuation



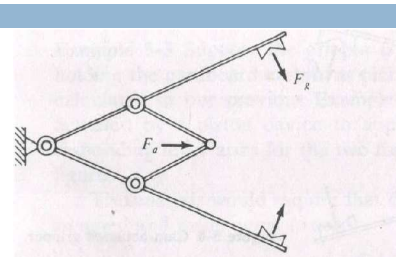
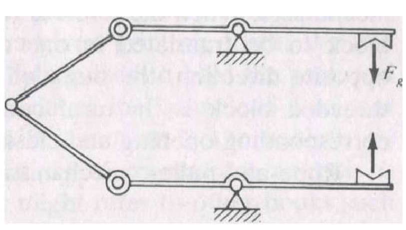
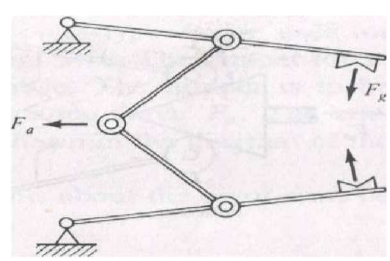


Figure 5-6 Some possible linkages for robot grippers.





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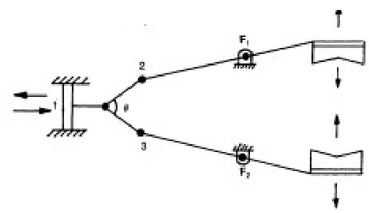
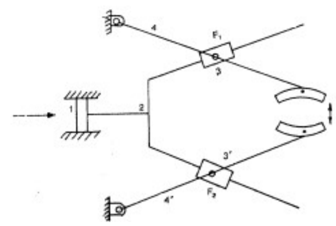
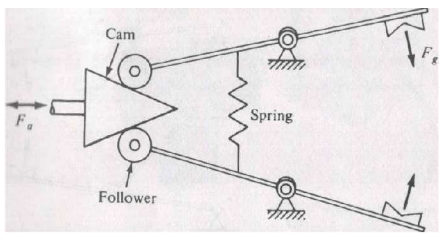
Linkage Actuation







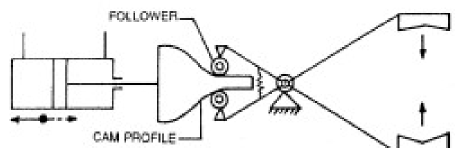


FIG. 4.9 *Cam actuated gripper*

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Linkage Actuation

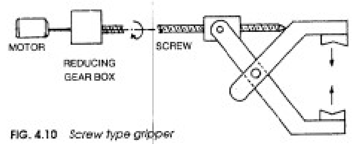
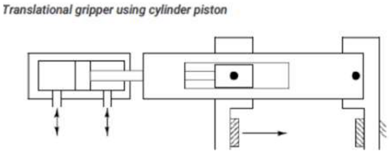
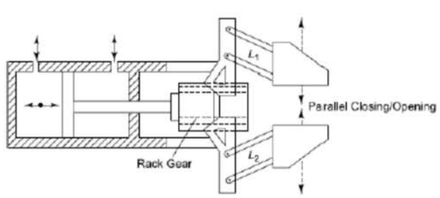


FIG. 4.10 *Screw type gripper*

Translational gripper using cylinder piston



Translational gripper using parallel bar linkages



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Gripper Actuations

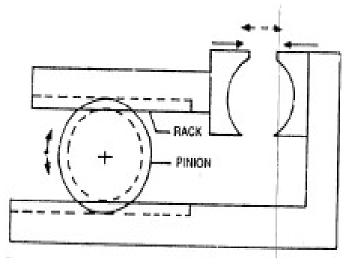
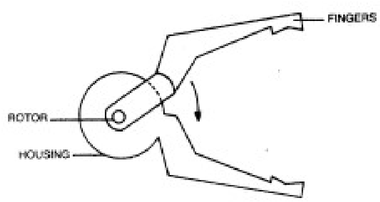


FIG. 4.13 Translational gripper using rotary actuators



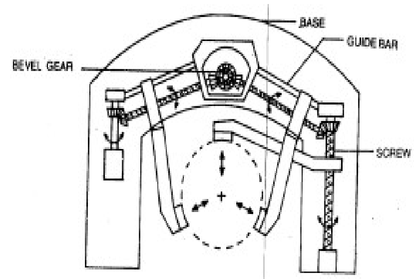


FIG. 4.14 Gripper using three point chuck mechanism

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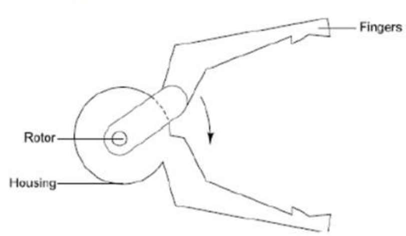
Gripper with a rotary actuator



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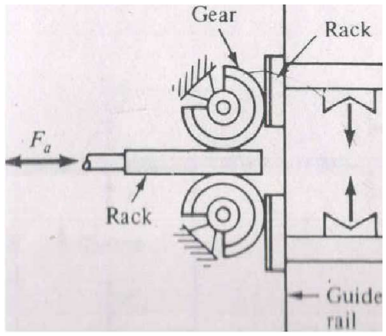
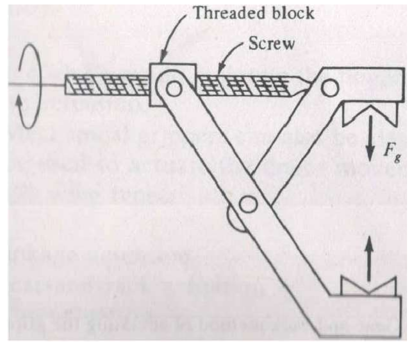
Gear & Rack & Cam Actuation





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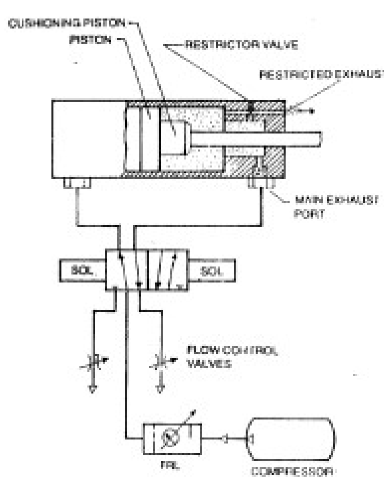

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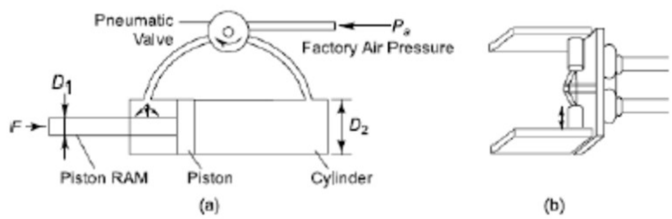
Designing Piston-Cylinder in the Pneumatic Gripper



$$F = P_a \times \frac{\pi D_2^2}{4} \qquad D_2 = \sqrt{\frac{4 \times F}{\pi P_a}}$$

where D_2 = Piston diameter, mm

P_a = supply pressure, kgf/mm^2

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VACUUM GRIPPERS

- Large flat objects are often difficult to grasp. One solution to this problem is the use of vacuum gripper.
- Vacuum grippers are used for picking up metal plates, pans of glass, or large lightweight boxes.
- Since the vacuum cups are made of elastic materials, they are complaint.
- The gripper is tolerant of errors in the orientation of the part and is especially suited for pick and- place work.
- For handling softer materials, cups made of harder material are used.

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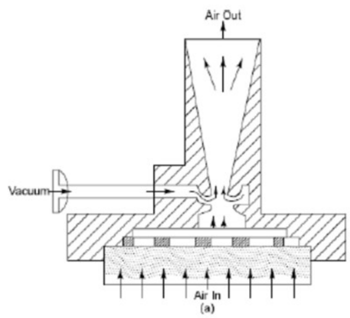
- A typical vacuum cup gripper is shown in Fig. a
- It is used extensively for lifting fragile materials.
- A compressed air supply and a venturi are used to create a gentle vacuum that lifts the part.



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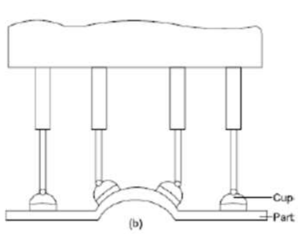
- The lift capacity of the suction cup [Fig. (b)] depends on the effective area of the cup and the negative air pressure between the cup and the object. The relationship can be shown by the equation:



$$F = KPA_c = KA_c\,(P_a - P_{res})$$

here

F = force or lift capacity, N

P = negative pressure, N/cm^2

A_c = total effective area of the suction cup(s) used to create the vacuum, cm^2

K = a coefficient depending on atmospheric pressure and conditions of seal

p_a = the atmospheric pressure and

p_{res} = residual pressure in vacuum-cup.

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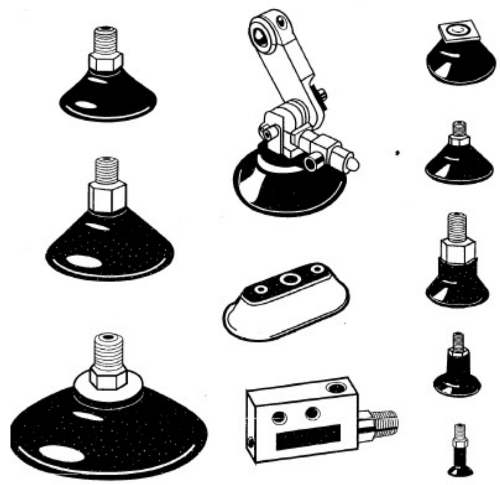
Vacuum Cups



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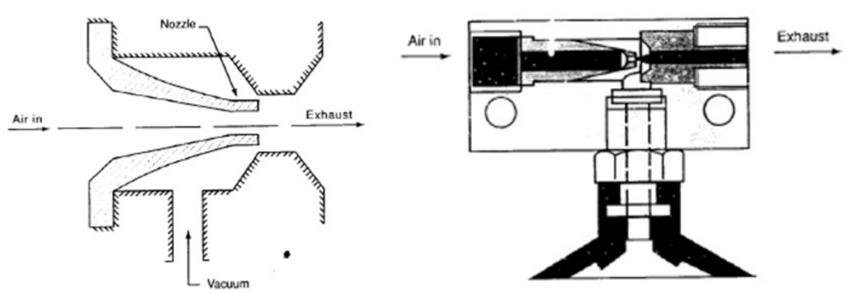
Vacuum Cup with Venturi device



(a) (b)

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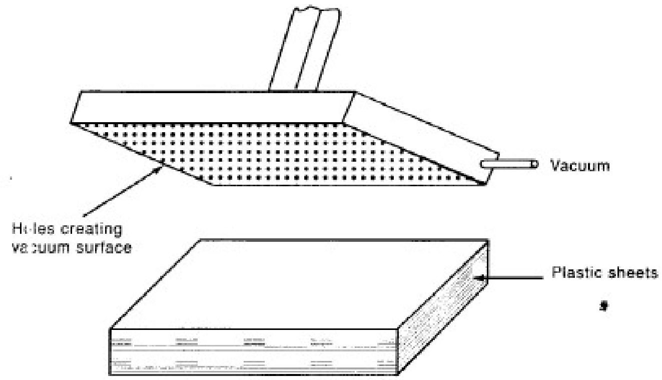
Vacuum Gripper



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Magnetic Gripper

Magnetic

Magnetic devices can handle ferromagnetic materials. The material can be lifted in the form of a sheet or plate with an electromagnet mounted on the robot tool plate. Figure 5.4.5 shows a single magnetic gripper and a dual magnetic gripper.

Magnetic grippers are similar in operation to vacuum grippers. However, instead of using vacuum to pick up the object, they employ a magnetic field created by an electromagnet or permanent magnet. Objects that have a flat, smooth, clean surface are the easiest to handle. The advantages of using magnetic grippers are:

1. Pickup times are very fast.
2. Part-size variations can be tolerated.
3. They are able to handle metal parts with holes.
4. They require only one surface for gripping.

The disadvantages with magnetic grippers include:

1. The residual magnetism remaining in the workpiece may cause problems in subsequent handling.

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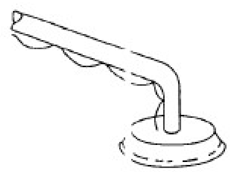
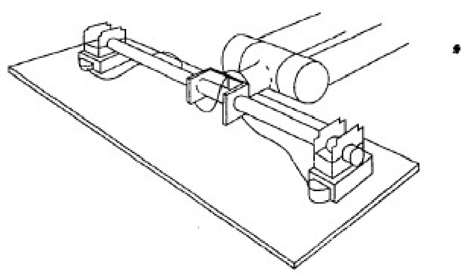
Magnetic Gripper


(a)


(b)

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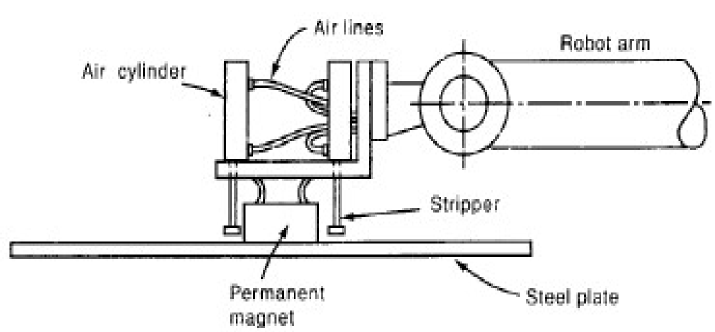
Permanent Magnet Gripper



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Permanent Magnet Gripper

- Permanent magnets do not require an external power and hence they can be used in hazardous and explosive environments, because there is no danger of sparks which might cause ignition in such environments.
- When the part is to be released at the end of the handling cycle, in case of permanent magnet grippers, some means of separating the part from the magnet must be provided.

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Magnetic grippers

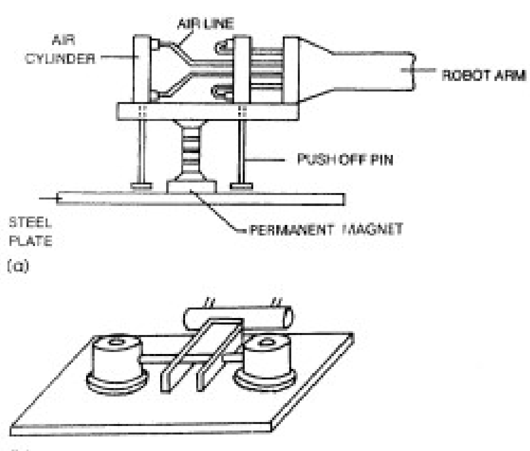

FIG. 4.15 Magnetic grippers (a) Permanent magnet type (b) Electro-magnet type

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Electromagnetic Gripper design

$$P = \frac{(IN)^2}{25A_c(R_a + R_m)}$$

where

IN = Number of amp-turns of coil

A_c = Area of contact of an object with magnet

R_a, R_m = Reluctances of magnetic paths through air and metal respectively

$$P \geq (a + g)m \times FS$$

where

a = gripper acceleration

g = gravitational constant

m = mass and FS = Factor of safety

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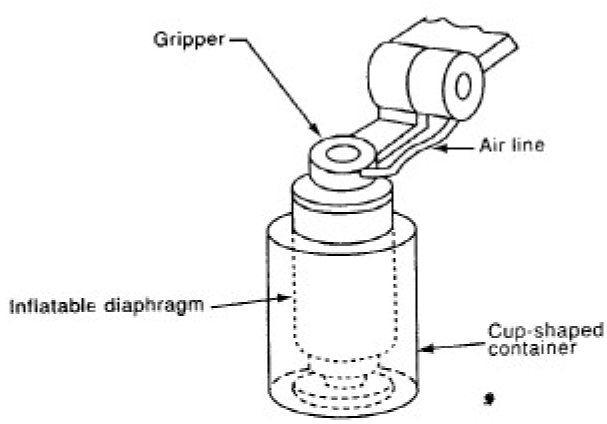
Inflatable Gripper



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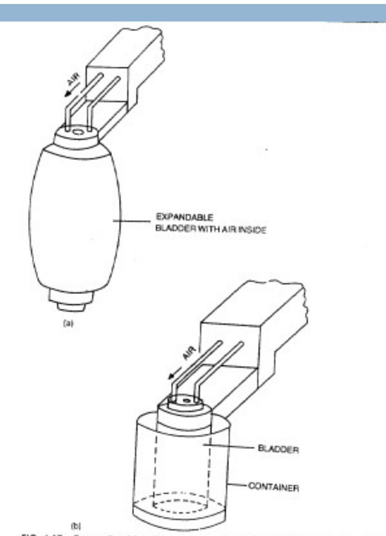

FIG. 4.17 Expanding bladder for gripping internal surface (a) Bladder fully expanded (b) Bladder inside the container

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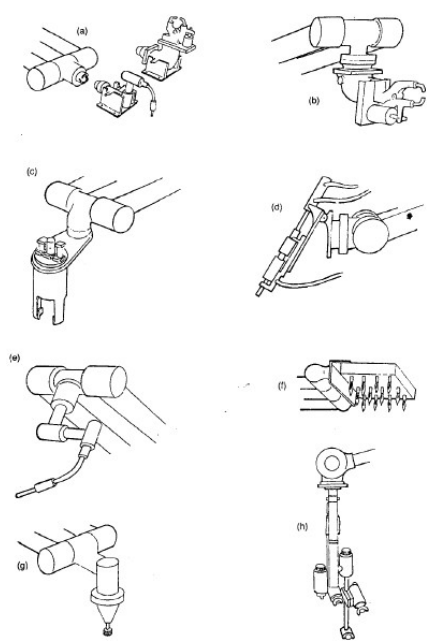
Toolings



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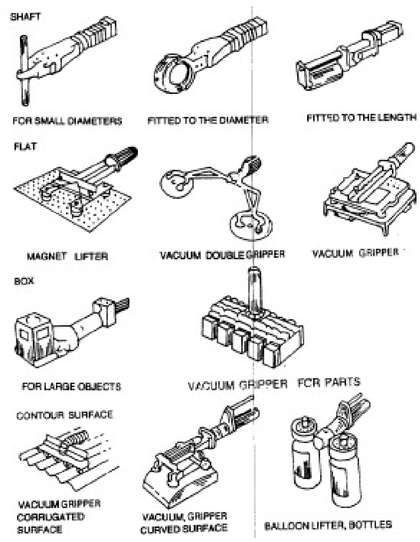
Toolings



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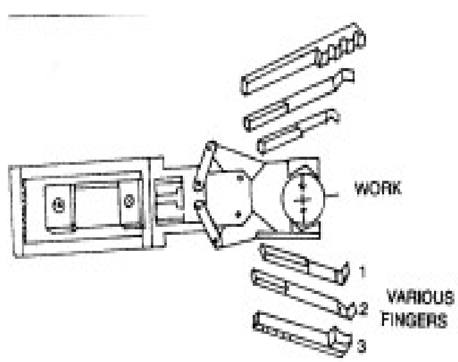
Modular Mechanical Gripper



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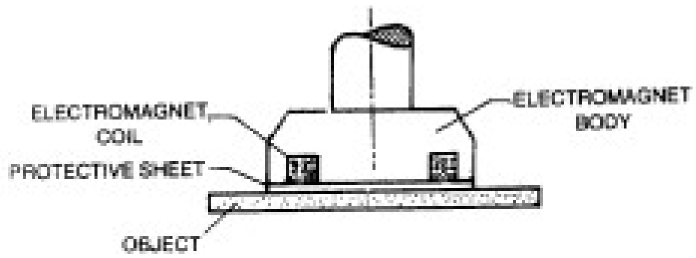
Electro Magnetic Gripper



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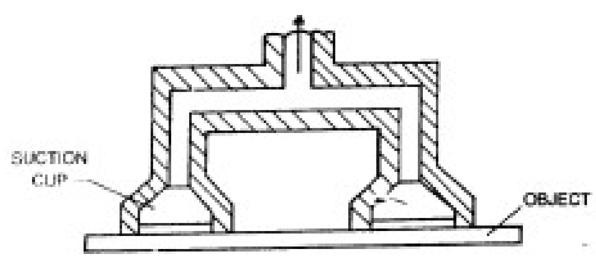
Vacuum Gripper



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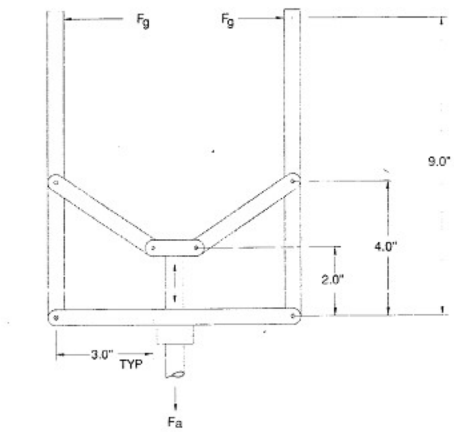

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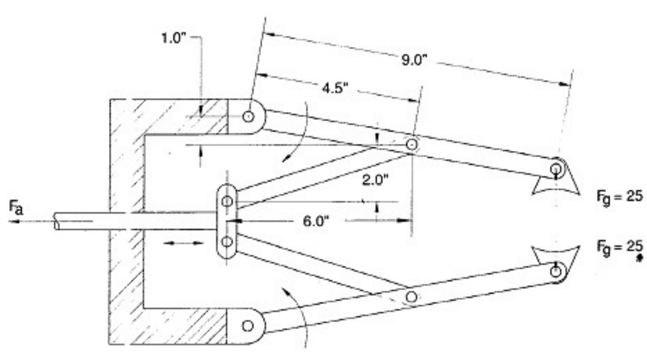

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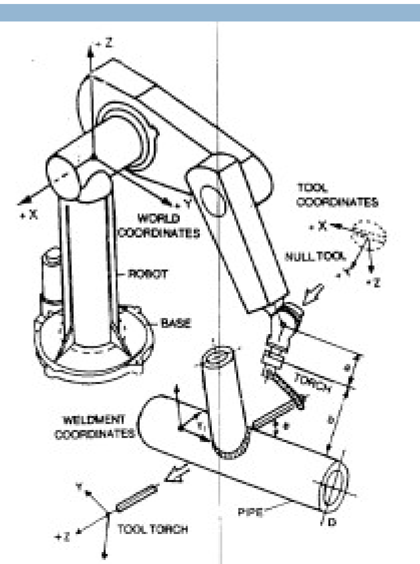
Robot with welding gun



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Vacuum Cups

- Vacuum surfaces are just an extension of the vacuum cup principle. In some material-handling applications the product to be lifted is not ridged enough for vacuum cups to be effective.
- To lift such material as cloth, paper, and plastic into place, a vacuum surface is used.
- The vacuum gripper consists of a flat surface with tiny holes that forms one side of a vacuum chamber.
- Each hole in the vacuum surface provides a small lifting force so that the flexible cloth, paper, or plastic would be held into place against the vacuum surface from many points.

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- Vacuum grippers are usually venturi devices, applying Bernoulli's principle to create suction by using compressed air.
- The vacuum generator and venturi block (miniature vacuum pump) are two common devices used for this purpose.
- The vacuum generator is a piston-operated or vane-driven device powered by an electric motor, and it is capable of creating a relative high vacuum.
- The venturi on the other hand is a simple device, as shown in Figure.

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Suction cup

The advantages for using suction cup grippers are:

1. They require only one surface for grasping the part.
2. They apply a uniform pressure on the surface of the part.
3. They require a relatively lightweight gripper.
4. They are applicable to a variety of different materials.
5. They have a significantly low cost.

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SPECIAL-PURPOSE GRIPPERS

- Hook grippers can be used to handle containers of parts and to load and unload them from overhead conveyors, Obviously, the items must have some sort of handle to enable the hook to hold it.
- Scoop and ladle grippers can be used to handle certain materials in liquid or powder form.
- A tool for ladling hot material. such as molded metal, is shown in Figure.
- One of this method's limitations is that the amount of material being scooped by the robot is sometimes difficult to control.

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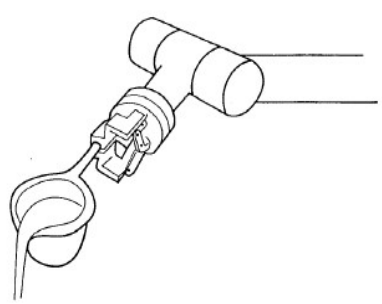
Scoop and ladle



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- Collet grippers are used to pick and place cylindrical parts that are uniform in size.
- They obtain 360 degree of clamping contact with strong force for rapid part transfer.
- They are used for grinding and deburring operations.
- Collet grippers are available in round, square, or hex shapes. Figure shows a round collet gripper.

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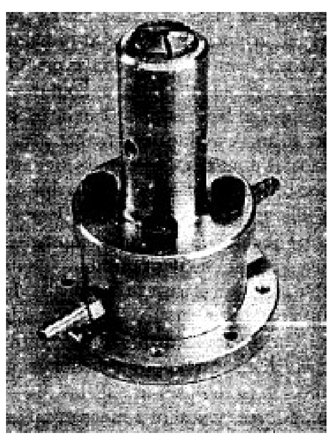
Collet grippers



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Inflatable grippers

- Inflatable grippers have an inflatable diaphragm that expands to grasp the object.
- The inflatable diaphragm is fabricated out of rubber or other elastic material, which makes it appropriate for gripping fragile objects.
- The gripper applies a uniform grasping pressure against the surface of the object rather than a concentrated force typical of a mechanical gripper.
- Figure shows an inflatable diaphragm grasping the inside diameter of a cup-shaped container.

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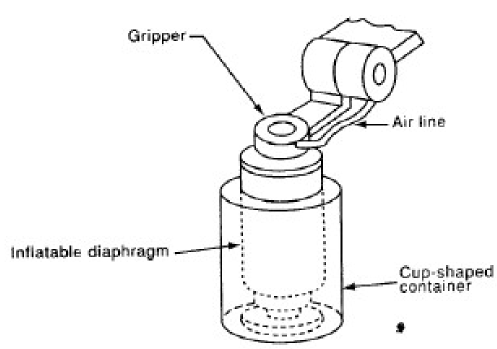
Inflatable grippers



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Expandable grippers

- Expandable grippers are similar to inflatable grippers but with a two- or three-finger design.
- Primarily, they are used to clamp an irregular-shaped workpiece.
- There are two types of expandable grippers: one that surrounds objects, gripping them from the outside, and one that grips hollow objects from the inside.
- In both cases, they make use of a hollow rubber envelope or other plastic material that expands when pressurized.
- Expandable grippers are distributing even pressure on the part and are ideal for handling fragile parts or parts that vary a great deal in size.

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GRIPPER SELECTION AND DESIGN

1. The part surface to be grasped must be reachable.
2. The size variation of the part must be accounted for because this might influence the accuracy of locating the part.
3. The gripper design must accommodate the change in size that occurs between part loading and unloading.

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4. Consideration must be given to the potential problem of scratching and distorting the part during gripping.
5. If there is a choice between two different dimensions on the part, the larger dimension should be selected for grasping.
6. Gripper fingers can be designed to conform to the part shape by using resilient pads or self-aligning fingers.

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7.The important factors that determine the required grasping force are:

a. The weight of the object

b. The speed and acceleration with which the robot arm moves, and the orientational relationship

c. The physical constriction or friction that is used to hold the part

d. The coefficient of friction between the object and the gripper fingers

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PROCESS TOOLING

- Process tooling is an end effector designed to perform work rather than to pick and place a work part.
- In a limited number of applications, the process tooling is a gripper that is designed to grasp and handle the tool.
- The reason for using a gripper in these applications is that there may be more than one tool to be used by the robot in the work cycle.
- Process tooling refers to the general class of special end effectors that may be attached to the robot wrist.

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Welding Guns

- A spot-welding gun can be attached to the robot wrist to place a series of welds on flat or curved surfaces, Generally, a three-degree-of-freedom wrist is required because of the dexterity required for maneuvering the gun.
- Gas-metal-arc-welding (GMAW) and Flux-core arc welding (FCAW) are the most commonly used methods for arc welding with robots.
- A welding gun can be attached to the robot wrist that carries the gas and bare wire for GMAW or cored electrode filled with flux for FCAW The robot can position the welding gun for a single straight or curved run or use a weaving pattern for wider welds.
- Both methods are shown in Figures 1 and Figure 2

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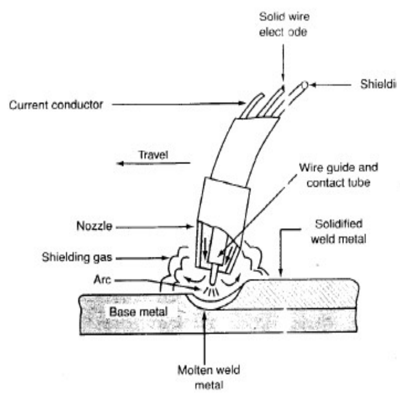
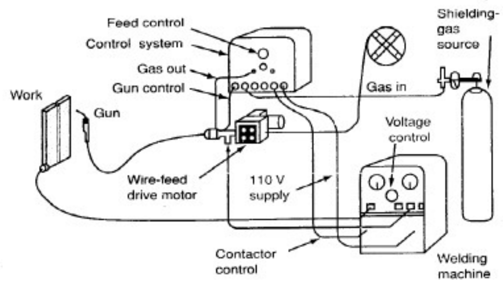
Gas Metal Arc Process





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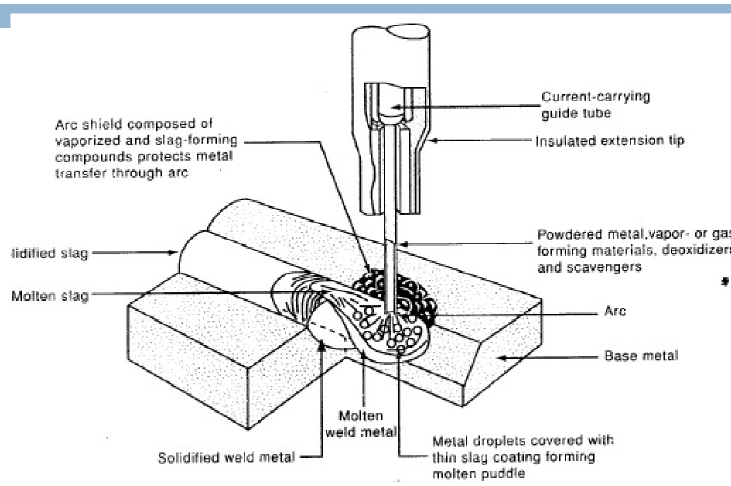
Flux-core arc welding



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Spray Painting/Grinding/Tooling

- Spray-painting guns are also commonly used by industrial robots.
- In some cases, only two degrees of freedom may be required of the robot wrist for spray painting. The robot can spray parts with compound curved surfaces.
- Grinders, routers, wire brushing, or sanders are also easily attached to a robot wrist.
- Liquid cement applicators, heating torches, and waterjet cutting tools can also be incorporated in the robot wrist.
- A large class of assembly tools, such as drills, screwdrivers, and wrenches, can be used by the robot. In some cases, these tools are automatically interchangeable by the robot.

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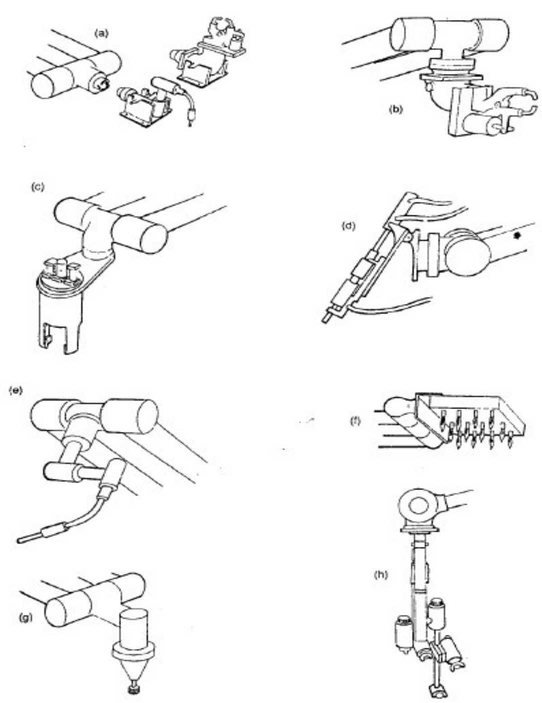

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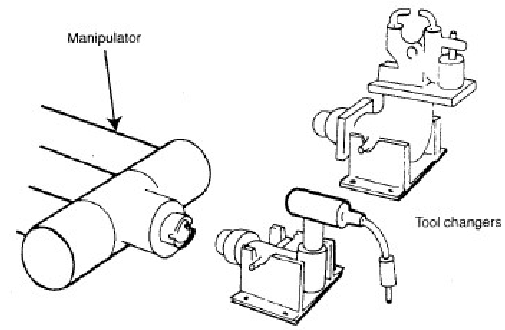
Tool Changers



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Compliance

- Compliance is a special end effector that is neither a gripper nor a process tool but rather a sensor or device that fits between the robot wrist and end effector for special assembly applications.
- In general, a compliant robot system is one that complies with externally generated forces to modify its motion for the purpose of alignment between mating parts.

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- If a robot uses a force sensor (piezoelectric, magnetic, or strain gauges) and modifies its control strategy based on that sensor's output, the term *active compliance* is used to describe the behavior.
- On the other hand, if the robot's gripper is constructed in such a way that the mechanical structure deforms to comply with those forces, the term *passive compliance is used*.

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- The general task of inserting a pin into a hole represents three types of contact during the process:

(a) The chamfer contact occurs when the pin is not perfectly aligned with the hole;

(b) if the pin is not rigid it will rotate slightly and start to slide and make a contact along one side of the hole; and

(c) if the misalignment is severe, the pin will make a two-point contact with the base of the pin and the far wall of the hole.

Figure shows how a misalignment of a pin into a hole results in an axial and lateral force, and a twisting moment by a contact force applied to the wrist sensor for correction. By moving in the correct direction with the compliance, the robot can reduce these forces on the pin.

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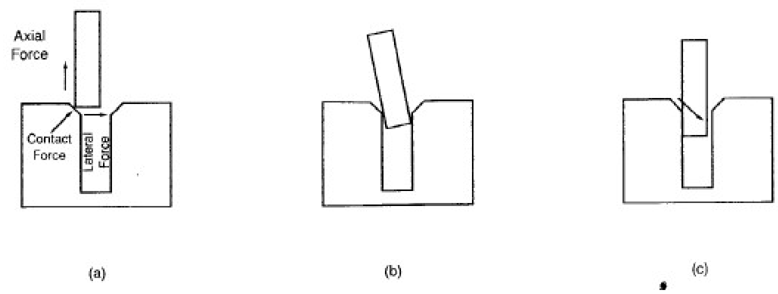
Compliance



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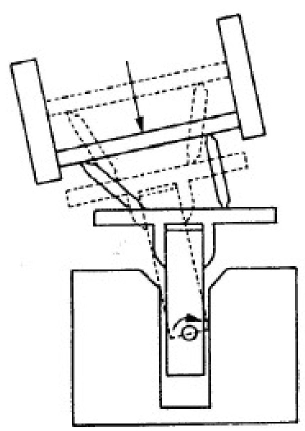
Remote Center Compliance



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Active compliance

- Active compliance systems as indicated earlier measure the active force and torque when the robot performs the programmed task and often are called *F/T sensing* systems.
- Force-sensing systems allow the robot to detect changes and variations in the workpiece or tooling during the operation and adapt the program to correct them.
- *F/T sensing uses an adaptor placed between the gripper and the* robot tool plate to measure the force and torque caused by contact between mating parts.

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Active Compliance

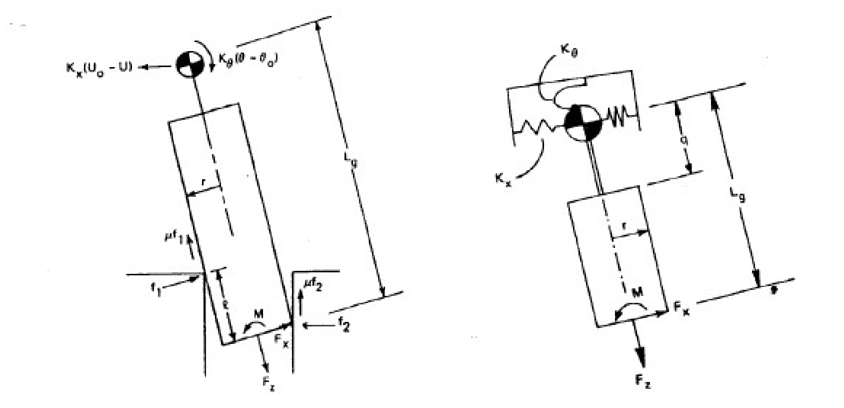

Figure 5.8.3 Active compliance: (a) forces acting on pin during two-point contact; (b) rigid peg supported compliantly by lateral springs K_x and angular spring K_θ at a distance *q* from peg's tip (*Source: ASME*)

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Force/Torque Active Compliance

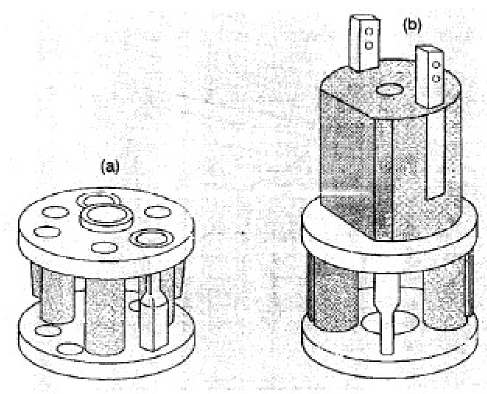

Figure 5.8.4 Force/Torque active compliance: (a) F/T transducer; (b) attached to the robot gripper

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Passive compliance

- Another approach to compliance is to allow the wrist to deform in such a way that the external forces are minimized.
- Passive compliance is using a spring-loaded wrist to provide the deformation. The concept of this principle applies to a Remote Center Compliance (RCC) device.
- This device was originally developed at the Charles Stark Draper Laboratories of Cambridge, Massachusetts, but now is available commercially in many forms by different manufacturers.
- The RCC device is a unique device that compensates for position errors due to machine inaccuracy, parts vibration, and fixturing tolerance.
- This minimizes the assembly forces and the possibility of parts jamming. Fig shows how the device works.

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- The original RCC device consists of three prates: The center plate is connected to the top plate with four rods and to the bo-tom plate with four additional rods.
- In operation, four rods, one on each corner, are used for lateral compliance (only two rods are shown in Figure), and four angled rods, one on each corner, are used for rotational compliance (again, only two rods are shown).
- The flexible rods allow the plates to move relative to each other and provide a combination of lateral and rotational compliance; however, this device is rigid in the axial direction with no compliance provided.

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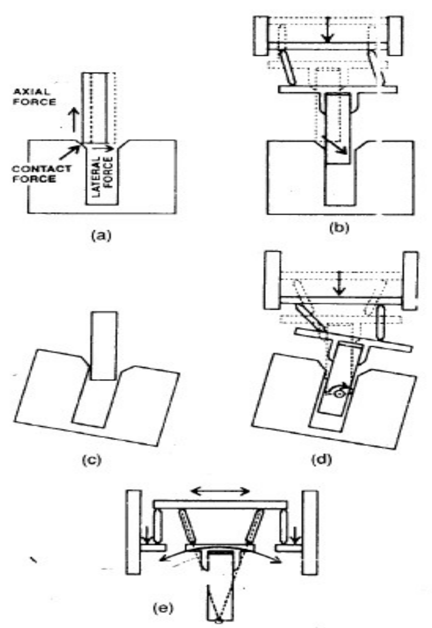

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Selection & Design of Gripper

- Part to be Handled
  - Weight and size
  - Shape
  - Changes in shape during processing
  - Tolerances on the part size
  - Surface condition, protection of delicate surfaces
- Actuation Method
  - Mechanical grasping
  - Vacuum cup
  - Magnet
  - Other methods (adhesives, scoops, etc.)

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- Power & Signal Transmission
  - Pneumatic
  - Electrical
  - Hydraulic
  - Mechanical
- Gripper Force
  - Weight of the object
  - Method of holding (physical constriction or friction)
  - Coefficient of friction between fingers and object
  - Speed and acceleration during motion cycle

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□ Positioning	Length of fingers Inherent accuracy and repeatability of robot Tolerances on the part size
□ Service Conditions	Number of actuations during lifetime of gripper Replaceability of wear components (fingers) Maintenance and serviceability
□ Operating Environment	Heat and temperature Humidity, moisture, dirt, chemicals
□ Temperature Protection	Heat shields Long fingers Forced cooling (compressed air, water cooling, etc.) Use of heat-resistant materials

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Strength, rigidity, durability
Fatigue strength
Cost and ease of fabrication
Friction properties for finger surfaces
Compatibility with operating environment

Use of interchangeable fingers
Design standards
Mounting connections and interfacing with robot
Risk of product design changes and their effect on the gripper design
Lead time for design and fabrication
Spare parts, maintenance, and service
Tryout of the gripper in production

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Length of fingers
Inherent accuracy and repeatability of robot
Tolerances on the part size

Number of actuations during lifetime of gripper
Replaceability of wear components (fingers)
Maintenance and serviceability

Heat and temperature
Humidity, moisture, dirt, chemicals

Heat shields
Long fingers
Forced cooling (compressed air, water cooling, etc.)
Use of heat-resistant materials

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Other Considerations

Use of interchangeable fingers
Design standards
Mounting connections and interfacing with robot
Risk of product design changes and their effect on the gripper design
Lead time for design and fabrication
Spare parts, maintenance, and service
Tryout of the gripper in production

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