Section 2 Design and assembly

Assembly details

DESIGN of assemblies and the processes that assemble them presents a chicken-and-egg problem. The production process cannot be well defined until the assembly is designed, but the assembly cannot be well designed until the process is defined. The difference between an economical assembly process and a costly failure lies almost entirely in the hands of the product designer, not the process designer.

Production costs are minimized when design and production engineering are coordinated. That is, when the least costly production process is selected and the product is designed for that process.

Suitability of a product for automatic assembly can be determined by an analysis that consists of three major steps for each component part in the assembly:

- Estimate the cost of handling the part automatically in bulk and delivering it in the correct orientation for insertion on an automatic-assembly machine.
- Estimate the cost of inserting the part automatically into the assembly and the cost of any extra operations.
- Decide whether the part must necessarily be separate from all other parts in the assembly.

Minimum parts

Assembly costs usually increase in proportion to the number of parts in the product. Therefore, no part should escape scrutiny, no matter how low its intrinsic value. Such parts as fasteners, clips, and washers may seem insignificant in themselves, but they add enormously to assembly cost. Taken as a group, they often account for the majority of assembly cost.

The cost influence of small parts is particularly evident in automatic assembly, because each part in the product requires a feeding and orienting device, a workhead, at least one extra work carrier, a transfer device, and an increase in the size of the basic machine structure.

For a part to be judged essential, it must satisfy one of three criteria:

- Does the part move with respect to all other parts already assembled?
- Must the part be made of a different material or be isolated from all other parts already assembled? (Only fundamental reasons concerned with material properties may be considered here.)
- Must the part be separate from all other parts already assembled because necessary assembly or disassembly would otherwise be impossible?

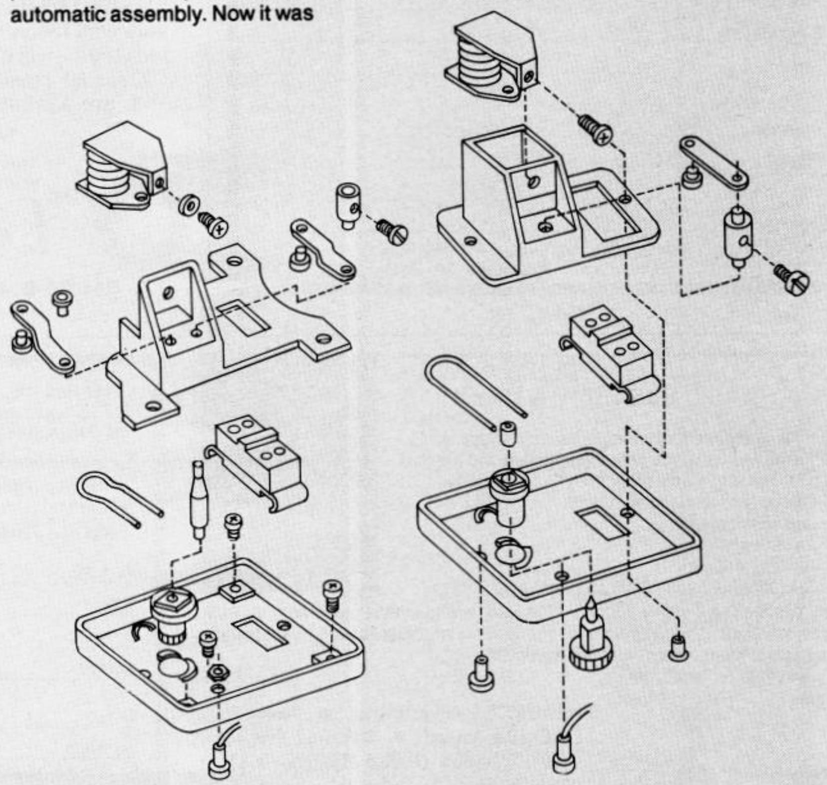
The criteria should be applied without regard to the apparent feasibility of eliminating parts or combining them with others. Feasibility and practicality are matters to be addressed by the designer after the analysis. The analysis itself indicates the possible directions for simplification and the cost benefits that result.

From manual to automatic assembly

In an evaluation of an immersion heater for automatic assembly initial analysis showed that of the 21 component parts in the original controller, 14 were unsuitable for automatic assembly. As a result, automation was uneconomical.

The controller was then redesigned and simplified, using information from the analysis. The new controller had 16 parts, of which only six were unsuited to automatic assembly. Now it was possible to automate the process, even though some manual assembly remained.

One or more parts of an assembly are often impossible to handle automatically, so the assembly machine includes manual workstations. The mixed automatic and manual assembly system saved about $150,000 per year in assembly costs.



Robot assembly

Products intended for robotic assembly can be analyzed in much the same way as those intended for manual assembly or automatic assembly.

The economic analysis that indicates whether manual, automatic, or robotic assembly is likely to be most economical can be shortened and made easier with the aid of newly developed computer programs. The design analysis of products intended for manual or automatic assembly has also been computerized. However, design analysis of robotically assembled products must still be carried out by paper and pencil.

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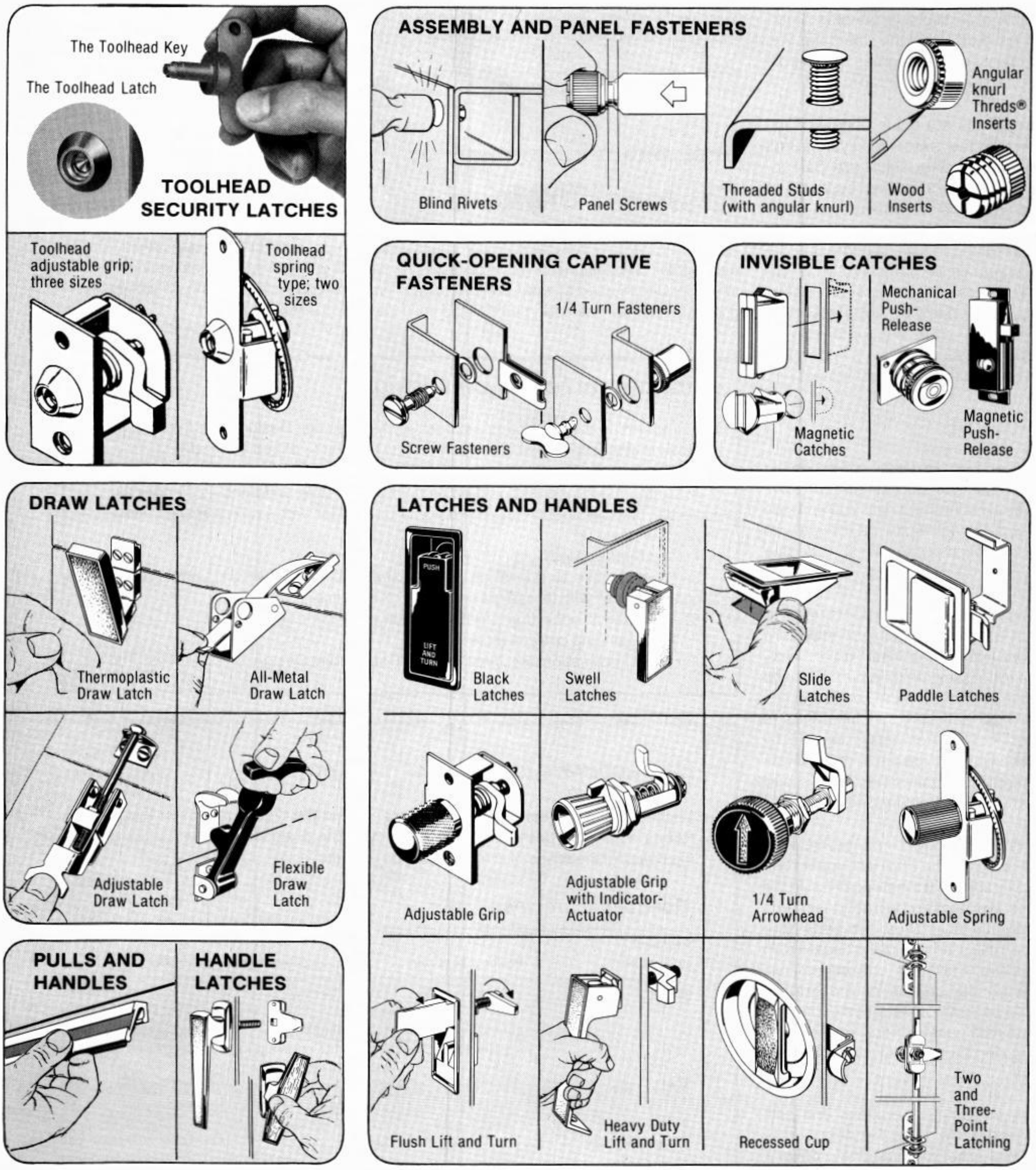

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Product analysis

The analysis system shows the effect of design decisions on the cost of robotic assembly. The system can be updated easily, so that changes in the cost, speed, or cycle time can be factored into the analysis.

The relative cost of the robot arms needed to assemble a particular product is determined by the difficulty of the insertions. It is affected mainly by the degrees of freedom needed to carry out the insertion.

Time estimates are made under the assumption that the assembly system has enough compliance to facilitate part insertions. The compliance may be built into the robot wrist, the work fixture, or both. Also, either the robot gripper or the work fixture is assumed to have sensors that detect the presence of parts and verify insertion. With these capabilities, stoppages caused by faulty parts do not present the major problems often encountered with dedicated automatic assembly systems and need not be included in time estimates.

Time analysis

The major barrier to design-for-assembly analysis is usually time. Design schedules are already so tight that additional analysis is precluded. Friendly software for use with common microcomputers eases this time pressure.

The present generation of robot arms typically takes 3 s to move, grasp, orient, return to the work fixture, and insert a part. Normally one robot arm inserts a part while the other grasps and moves the next part. The minimum time between part insertions is thus 1.5s. To allow for delays caused by interactions between the arms, the analysis assumes that the system time T_p for assembling a part with no problems is 2 s.

To carry out a gripper change, insert a part, and return to the original gripper, one arm typically spends 9 s instead of 3 s. In the worst case, the other arm will only insert one part during this time. Thus, two parts have been added in 9 s instead of the usual 4 s. In the best case, the other arm inserts two parts during the course of the gripper change. To accommodate these extremes, an average time penalty of 4 s is used in the analysis, giving a total of 6 s per part instead of 2 s.

In many assembly operations one part must be held down while the next part is added. If one robot arm must hold down a part while the other inserts a second part, then the system time for one part is lost. In general, then, if both arms are required, the system time for that part is 4 s.

Possibly the most important point to remember is that every part in a product requires assembly. Small, inexpensive, and seemingly insignificant parts such as fasteners often cost much more to assemble than larger, more complex parts. Such small items are often overlooked, yet they frequently account for much of total product cost.

Based on the MACHINE DESIGN articles: "Design for assembly: automatic assembly," Jan. 26, 1984, and "Design for assembly: robots," Feb. 23, 1984, by Professor Peter Dewhurst and Professor Geoffrey Boothroyd, University of Massachusetts, Amherst, MA.

Fastener preload

NO SIMPLE totally reliable formula exists that will tell the designer what size of fastener should be used at what preload for a given application. Fastener material and finish and absence or presence of a lubricant or coating in addition to the design parameters of the load all present variables that must be considered for each particular case. The only reasonably certain way to design a joint is to test the actual joint or a pilot assembly using accurate equipment.

However, a number of simplified techniques are commonly used. No "rule-of-thumb" technique should be relied on for exact design solutions, particularly if the joint is in an application where failure could cause injury or serious damage. These simplified methods are given only as a starting point in determining fastener size, material, and preload.

Possibly the easiest way to determine how much load a fastener can safely take is to tighten several samples with a torque wrench until they fail. All calculations for that fastener are then based on 75% of the average yield strength.

Principles of bolted joint design

1. Determine external loads as precisely as possible. Design such that external load is at least one-half but not more than two-thirds of bolt preload.
2. The dynamic force acting on the bolt must be below the material endurance limit.
3. Clamped members should be as rigid as possible and bolts as slender as possible. Flanges should be in metal-to-metal contact, with seals or sealant used in place of gaskets.
4. Use heat-treated bolts, ISO grade 8.8 or higher.
5. Preload bolts to a level above that specified in the design. Lubricate all friction surfaces with thread grease before preloading.
6. Retighten all bolts after proof testing, or early in the service life.
7. Avoid bending or transverse loading.

For more information see, "New Look at Bolted Joint Design," MD, June 20, 1985.

How accurate is the tightening tool?

The technique selected to tighten a fastener and the type of tool used to apply the torque contribute to the ultimate accuracy of the preload. The two tables give an indication of the range of error that can be expected.

Control Accuracies

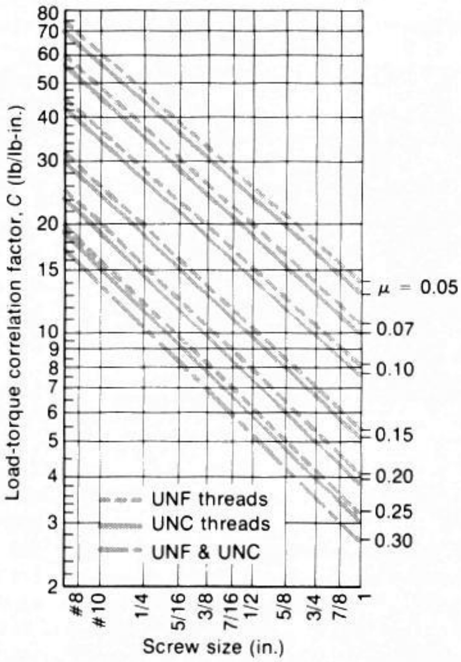
Element controlled	Preload accuracy	To maximize accuracy
Torque	±15% to ±30%	Control bolt, nut, and washer hardness, dimensions, and finish. Have consistent lubricant conditions, quantities, application, and types.
Turn	±15% to ±30%	Use consistent snug torque. Control part geometry and finish. Use new sockets and fresh lubes.
Torque and turn	±10% to ±25%	Plot torque vs turn and compare to previously derived set of curves. Control bolt hardness, finish, and geometry.
Torque past yield	±3% to ±10%	Use "soft" bolts and tighten well past yield point. Use consistent snugging torque. Control bolt hardness and dimensons.
Bolt stretch	±1% to ±8%	Use bolts with flat, parallel ends. Leave transducer engaged during tightening operation. Mount transducer on bolt centerline.

Estimating preload

A load-torque correlation graph gives a quick-and-dirty estimate of preload on nuts, bolts, and socket screws with UNF or UNC threads. The graph accounts for the effect of thread helix angle, but assumes that the coefficients of friction between mating threads is the same as that between abutment and fastener head.

To use the graph, start with nominal bolt size on the horizontal axis and read vertically to the curve representing the correct friction coefficient and thread type. Then read horizontally to find correlation factor *C*. To estimate preload, multiply *C* by the torque applied to the fastener.

For more detailed discussion of this technique see "Predicting Initial Bolt Load," MD, February 11, 1982.



Friction data

Bolt surface coatings	Friction coefficient, μ Lubricated	Nonlubricated
Organic with PTFE	—	0.08-0.15
Dry film with PTFE	0.07-0.11	—
Conversion	0.05-0.08	0.08-0.15
Organic	—	0.10-0.28
Electroplated Cd or Zn	0.07-0.14	0.12-0.25
Mechanically plated Cd/Zn or Cd/Sn	0.07-0.17	0.14-0.20
Organic/Inorganic	0.07-0.10	0.18-0.25

Test data from which this table was derived were provided by Elco Industries Inc. Report 000.056.1, by Allen Softley.

Typical Tool Accuracies

Type of tool	Element controlled	Typical accuracy range (% of full scale)
Slug wrench	Turn	1 Flat
Bar torque wrench	Torque Turn	±3 − 15% 1/4 Flat
Impact wrench	Torque Turn	±10 − 30% ±10 − 20%
Hydraulic wrench	Torque Turn	±3 − ±10% ±5 − 10°
Gearhead air-powered wrench	Torque Turn	±10 − ±20% ±5 − 10°
Mechanical multiplier	Torque Turn	±5 − 20% ±2 − 10°
Worm-gear torque wrench	Torque Turn	±0.25 − 5% ±1 − 5%
Digital torque wrench	Torque Turn	±1/4 − 1% 1/4 Flat
Ultrasonically controlled wrench	Bolt elongation	±1 − 10%
Hydraulic tensioner	Initial bolt stretch	±1 − 5%
Computer-controlled tensioning	Simultaneous torque and turn	±0.5 − 2%

Another simple method is to take two-thirds of the fastener's ultimate tensile strength as a value for how much tensile load it can safely take.

When introducing a safety factor note that if a bolt is selected with a yield strength that is four times the working load, it does not necessarily follow that the design will have a safety factor of four. In a rigid joint a safety factor of four is achieved only when the bolt is tightened to develop a clamping force four times the working load.

Flexible joints are quite different. A flexible joint can only be tightened to the working load. In the case of a flexible joint, a bolt must be selected to meet the requirements of the working load plus any added stress, all multiplied by the required factor of safety.

Assembly errors and the effects of load can accumulate so that preload values may drift either way, becoming a mere fraction or a significant multiple of the designed clamp load. A preload value allowed to drift too low results in only a small portion of the fastener clamp load being available to handle working load. Loosening or fatigue failure could result. Errors that accumulate and produce excessive clamping can cause premature tensile failure.

Tool Scatter: An error of ±10% could result if a common torque wrench with a ±5% error rating at full scale were used.

Operator Error: A conservative ±10% error is assumed, although often it is much greater.

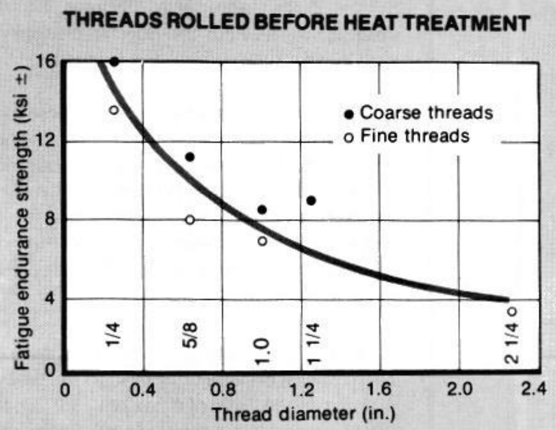
Control: Because torque is used to create tension, a high error of about ±30% could result. Tool control is one of the largest error sources.

Short-Term Relaxation: In the first few minutes after initial tightening, load loss from embedding typically ranges from 2% to 5%. Relaxation over the next few weeks may lower preload another 5%. An assumption of −8% total loss is reasonable.

External Load: If working load is on the order of 25% of preload, with a joint-to-bolt stiffness ratio of 3:1, external load is distributed as approximately 6% more bolt load and 19% less clamping force.

The overall result of these errors is a possible clamping force some 23% of nominal preload and a possible maximum bolt load 156% of nominal preload.

A clamping force that is only 23% of the nominal preload is likely to be inadequate to handle vibration and long-term relaxation. A bolt loaded to 156% of nominal preload would be more likely to fail under tensile load. If no action were taken to reduce error,



Fatigue endurance strength drops with increasing thread diameter, and is somewhat higher for coarse threads than for fine threads. Fasteners used in these tests had ultimate tensile stresses of 180 to 200 ksi, and were subjected to a mean static stress of 100 ksi. Values for fasteners with cut threads would be similar.

the fastener used in this hypothetical joint would have to accommodate a wide deviation in nominal load.

If the error producing factors are modified to a best possible situation, the clamping force might be improved to 86% and the maximum load reduced to 105%.

If a fastener designed only for nominal load had a diameter of one in., for worst conditions, the fastener would have to be 2¼ in. and for improved condition, 1¼ in.

For a more detailed discussion of preloads and avoiding joint failure, see "Fastener Groups Seek Answers to Bolted Joint Problems," MD, July 26, 1984; "Evaluating Loads in Bolted Joints," MD, June 21, 1984; "How Much Prestress for Bolted Joints," MD, Aug 11, 1983; "Force Calculations for Bolted Joints," MD, August 25, 1983; "Hidden Fastener Loads," MD, August 25, 1983; "Avoiding Failure in Bolted Joints," MD, May 20, 1982; and "A Practical Guide to Bolt Analysis," MD, April 9, 1981.

Fastener fatigue

Fatigue strength of threaded fasteners depends not only on the fastener material and preload, but also on the fastener diameter and the way it was manufactured. No one completely understands the physical mechanisms that reduce fatigue endurance with increasing diameter; however, considerable experimental evidence indicates that the effect is real. The mechanisms that seem to account for the effect include metallurgical properties, characteristics of the forging/and cold-heading processes, and characteristics of the thread-forming process.

Fatigue tests have recently been conducted on large-diameter fasteners, using fastener diameter, preload, and thread-manufacturing methods as the primary test variables.

In general, the tests demonstrate that large-diameter fasteners have only about one-third to one-half the fatigue endurance strength of smaller diameter fasteners for given thread manufacturing techniques and joint types. However, fasteners with threads rolled after heat treatment have about three times the fatigue endurance strength of fasteners with cut threads in open joints and about 15% higher strength in closed joints.

For a more detailed discussion of fastener fatigue, see "New Data on Fastener Fatigue," MD, April 22, 1982.

Materials

FASTENERS are available in a wide range of engineering material. Selection is normally based on such considerations as: environment (corrosive or temperature extremes), weight, magnetic properties, stresses, reusability, and life expectancy.

For the greatest economy, standard materials should be used. Specifying a fastener material with a specific chemical analysis adds time and cost. Often a standard fastener can be altered by heat treating, cold working, or coating to meet special needs.

Steel: Most fasteners are made from steel. Specifications cover a broad range of mechanical properties that are indicated by a bolt-head marking system that identifies the fastener by grade. For example, SAE grades 2, 5, and 8 are most often specified. Commonly used steels are: SAE 1010 (machine screws, carriage bolts and other fasteners without critical strength requirements); SAE 1018, 1020, 1021 (bright cap screws, special items); SAE 1038 (high-strength bolts, studs, nuts, cap screws); SAE 1041, 1045, 1330, 1340 (special high-strength requirements), and SAE 1100 series (resulfurized—usually for nuts).

Aluminum: The family of aluminum alloys is the least costly, by volume, of all fastener metals. Aluminum fasteners are classified as hardenable and nonhardenable and weigh about one-third as much as steel. Some grades equal or even exceed the tensile strength of mild steel. The metal polishes to a high luster, has high thermal and electrical conductivity, is nonmagnetic, can be hardened by alloying, and has high corrosion resistance. Typical fastener alloys are 2024-T4 (cold-formed bolts, screws, rivets, machine-screw nuts), 2011-T3 (milled-from-bar nuts, screws, bolts), 1100 (cold-formed rivets), and 6061-T6 (nuts).

For more details on aluminum fasteners see, "Design Factors for Threaded Aluminum Fasteners," MD, June 26, 1980.

Brass: This metal is easily worked into shape and has adequate strength. Tensile strength or hardness can be improved by cold working. Some brasses also have a greater tensile strength than mild carbon steel, along with a higher resistance to corrosion. The metal is nonmagnetic and takes a high luster.

Copper: One of the most malleable of all metals, copper can be worked into a wide variety of shapes. It has good corrosion resistance and the highest conductivity of all the nonprecious metals.

For greater strength copper is alloyed with silicon, and manganese or aluminum. Lead is added to give free-machining qualities. Typical alloys are high-silicon bronze, type A (hot-forged bolts, nuts; milled-from-bar bolts, nuts, set screws); low-silicon bronze, type B (cold-formed bolts, nuts, rivets, screws); silicon-aluminum bronze (hot-forged products requiring special properties); and cupro-nickel, a copper-nickel used for high strength and resistance to salt-water corrosion.

Nickel: Fasteners can be made from commercially (99.4%) pure metal, Monel, or Inconel. They are typically used where toughness, immunity to discoloration and corrosion, and strength at high temperatures are desired.

Monel. Combines relative economy with adaptability to cold heading and roll threading.

Nickel. Ideal for applications involving contamination, and the strength retention at both high and subzero temperatures.

Inconel. Excellent for fasteners that must retain high strength and resistance to oxidation at temperatures up to 1,600° F.

Stainless steels: Fasteners of this metal are used where corrosion, temperature, and strength are problems. They also produce a mirror-like finish. There are three basic types:

Fastener finishes and coatings

Coating or finish for fasteners	Used on	Corrosion resistance	Characteristics
Anodizing	Aluminum	Excellent	Frosty-etched appearance.
Black oxide, blued	Steel	Indoor satisfactory, outdoor poor.	Black, can be waxed or oiled.
Black chromate	Zinc-plated or cadmium-plated steel	Added corrosion protection on plated surfaces	Black, semilustrous. Used for decorative outdoor purposes. Can be lacquered.
Blueing	Steel	Indoor satisfactory, outdoor poor.	Decorative use. Blue to black, can be waxed or oiled.
Brass plate, lacquered	Steel, usually	Fair	Brass finish which is lacquered. For indoor decorative use.
Bronze plate, lacquered	Steel, usually	Fair	Color similar to 80% copper, 20% zinc alloy. Lacquered finish. Recommended for indoor decorative use.
***Cadmium plate**	Most metals	Excellent	Bright silver-gray, dull gray, or black finish. For decoration and corrosion protection (especially applications).
Clear chromate finish	Cadmium and zinc-plated parts	Very good to excellent	Clear bright or iridescent chemical coating for added corrosion protection, coloring, and paint bonding. Colored coatings usually provide greater corrosion resistance than the clear.
Dichromate	Cadmium and zinc plated parts	Very good to excellent	Yellow, brown, green, or iridescent colored coating same as clear chromate.
Olive drab, gold, bronze chromate	Cadmium and zinc-plated parts	Very good to excellent	Green, gold, or bronze tones same as clear chromate.
Chromium plate	Most metals	Good (improves with increased cooper and nickel undercoats)	Bright blue-white, lustrous finish. Relatively hard surface used for decorative purposes.
Copper plate	Most metals	Fair	Used for nickel and chromium-plate undercoat. Can be blackened and relieved to obtain Antique, Statuary, and Venetian finishes.
Copper, brass, bronze, misc. finishes	Most metals	Indoor, very good	Decorative finishes. Applied to copper, brass, bronze-plated parts to match colors. Tones vary from black to almost the original color. Finish names are: Antique, Black Oxide, Statuary, Old English, Venetian, Copper Oxidized
Lacquering, clear or color-matched	All metals	Improves corrosion resistance. Some types suitable for humid or other severe applications.	Decorative finishes. Clear or colored to match mating color or luster.
Lead-tin	Steel, usually	Fair to good	Silver-gray, dull coating. Gives good lubrication to tapping screws.

All of these finishes require a coating of lacquer to prevent color change. *Indications are that the use of cadmium may be restricted.

Martensitic. Magnetic and hardenable. Common fastener alloys are Type 410, 416, and 431.

Ferritic. Magnetic and not hardenable by heat. Can be cold worked with reasonably good results. Used for economic reasons, and where corrosion-resistance requirements are not too severe. Best fastener alloy types are 430 and 430° F.

Austenitic. Nonhardenable, nonmagnetic, and offer the greatest degree of corrosion resistance. Typical alloys are 18-8 and 300 series.

Titanium: The lightweight, high-strength fasteners made from this material are used chiefly in aircraft. This material has excellent corrosion resistance and good high-temperature performance. Titanium fasteners are most commonly used in joints loaded in shear but are also used in tension-loaded joints.

Beryllium: Exceptionally lightweight, fasteners of beryllium are about 40% as heavy as titanium. Brittleness is a limitation to widespread use. Beryllium bolts are used primarily for applications where the shear requirement is at least 60 ksi.

Nonmetallic materials: These are covered in the section on plastic fasteners.

Temperature ranges

Super alloys and exotic metals are now used to make fasteners that withstand high temperatures. Austenitic alloys are the primary types for use at elevated temperatures. They include nonheat-treated alloys such as the SAE 30300 series of stainless steels, Hastelloy, Inconel, and Monel and precipitation-hardening alloys, such as AMS 5725, and 17-7PH.

Hot-heading techniques have produced fasteners that have physical properties satisfactory for use at 1,500°F.

Mechanical fasteners, chiefly those made from refractory metal, are used for short-time (usually only a few hours) exposure to temperatures up to 3,000°F. Columbium fasteners are usable in the 2,000 to 2,600°F range and tantalum is preferred for the 2,800 to 3,600°F bracket. Tungsten is the only fastener material that will survive above 3,600°F despite its susceptibility to severe oxidation if uncoated.

Coatings, and the maintenance of their integrity throughout the life of the bolt, remain the single biggest problem with refractory metal bolts. Deterioration of existing coatings with time can lead to catastrophic oxidation of any of the refractory metals at these temperatures.

At cryogenic temperatures, threaded fasteners made from nickel and iron-base alloys have excellent mechanical properties.

Finishes and coatings

Coatings or special finishes on a fastener improve appearance, increase corrosion resistance, and provide lubricity. Selection is based on:

- Whether the coating or finish is for decoration or protection, or both.
- Type of material, or plated surface on mating parts.
- Color match, if any.
- Limits on type of fastener material.
- Type of in-service corrosion.
- Availability of finishing process.
- Cost.

Electrodeposited coatings: Zinc, cadmium, tin, nickel, and chromium coatings are most common for fasteners. Zinc is preferred for industrial atmospheres. Cadmium is best in marine atmospheres but it is more expensive than zinc. A protective film of corrosion products forms on zinc and cadmium surfaces; but the film on cadmium will wash off in rain.

Tin plating does not effectively protect ferrous products from atmospheric corro-

Fastener finishes and coatings

Coating or finish for fasteners	Used on	Corrosion resistance	Characteristics
Bright nickel	Most metals	Indoor excellent. Outdoor good if thickness is at least 0.0005 in.	Silver finish used for appliances, hardware.
Dull nickel	Most metals	Same as bright nickel	Whitish cast.
Passivating	Stainless steel	Excellent	Removes iron particles and produces a passive surface.
Phosphate Bearing Surfaces, Army 57-0-2, Type II, Class A	Steel	Good	Antichafing properties used on sliding or bearing surfaces.
Phosphate Rust Preventive, Army 57-0-2, Type II, Class B	Steel	Fair to good	Rustproofs steel. Plain grayish surface. Rust-preventive oils can be applied over it. Can be dyed black.
Phosphate Paint-base Preparations, Army 57-0-2, Type II, Class C	Steel, aluminum, zinc plate	Good, after paint or lacquer applications	Plain gray. Prepares steel, aluminum, and zinc-plated parts for painting or lacquering. Increases bond between metal and coating.
Colored phosphate coatings	Steel	Superior to regular phosphated and oiled surfaces.	Increases corrosion resistance. Available in green, red, purple, blue, black, etc.
Rust preventives	All metals	Varies with function of oil	Various colors. Usually applied to phosphate and black oxide finishes to protect parts in transit or prolonged storage.
Silver plate	All metals	Excellent	Decorative, expensive. Excellent electrical conductor.
Electroplated tin	All metals	Excellent	Silver-gray color. Excellent corrosion protection in contact with food.
Hot-dip tin	All metals	Excellent	Silver-gray. Thickness hard to control, especially on fine-thread parts.
Electroplated zinc	All metals	Very good	Bright blue-white, gray coating.
Electrogalvanized zinc	All metals	Very good	Dull grayish color used where bright appearance is not wanted.
Hot-dip zinc	All metals	Very good	For maximum corrosion protection. Dull grayish color. Use where coating thickness not important.
Hot-dip aluminum	Steel	Very good	For maximum corrosion protection. Dull grayish color. Use where coating thickness not important.

All of these finishes require a coating of lacquer to prevent color change. *Indications are that the use of cadmium may be restricted.

sion, but it is good for fasteners in contact with food. Nickel coatings resist some chemicals and remain attractive for a long period.

Electroplating a threaded fastener can change the thread fit. Allowance must be made for this change in dimensions.

Mechanical plating: Fasteners are coated by tumbling in a drum that contains powdered zinc or cadmium and glass shot.

In contrast to electrodepositing, which can be irregular, mechanical coatings are uniform on flat surfaces, except near the edges, where the plating is thinner.

Chemical-conversion coatings: Phosphate coating gives a corrosion-resistant deposit. Usually, fasteners are dipped in a solution of zinc or manganese phosphate and processed through tumbling barrels. Phosphate coating is less expensive than zinc or cadmium plating, especially when heavy deposits are required. Phosphate, like cadmium, adds lubricity.

Chromate treatment considerably increases corrosion resistance at nominal cost. It is particularly effective in drying of moisture, and preventing rusting between mated parts.

Chromate films should, however, not be specified on fasteners continuously subjected to rainfall or running water.

Organic coatings: Provide a tight film barrier against corrosive attack and, unlike platings, are not sacrificial. Protection is about twice that afforded by zinc and cadmium platings. Also, the organics enable a fastener manufacturer to color code different sizes and to avoid the hydrogen embrittlement common to platings.

Early organic finishes were based on alkyd and phenolic paints, modified with low flash-point solvents to enable them to rapidly form a protective film in bulk application processes. New coatings based on an alloy of fluorocarbon and other polymers provide lubricity in addition to increased barrier protection. The inherent lubricity of these coating enables users to very accurately set joint preloads and to reduce runup torque in automatic equipment.

Hot-dip coatings: Aluminum (aluminized) and zinc (galvanized) are commonly used in this method to provide low-cost protective coatings for inexpensive, high-strength, ferrous fasteners. Tin coatings provide excellent corrosion resistance. Thicknesses are difficult to control, but some tinners claim excellent results, even on fine threads.

Microencapsulation: Plating build up should be considered when specifying fastener dimensions. Fluids, stored in microcapsules, are released under controlled conditions to improve the corrosion resistance.

For more details on coatings see, "Fighting Corrosion in Fasteners," MD, February 26, 1981

Automatic assembly

ACCORDING to the Industrial Fasteners Institute, more than 50% of total production time is spent on the assembly or fastening function. However, mechanical fastening usually represents less than 5% of the total in-place or assembled cost of a product.

When automatic assembly is part of the manufacturing process, the type of fastener or fastening method selected must not only meet the product's requirements but also be compatible with the assembly machinery.

Successful automatic assembly applications are characterized by:

- Dimensional consistency on all components and fasteners. Tolerances required for automatic assembly may exceed those required by the product.

- Stable design that is not changed frequently, or "family" designs which can be easily programmed.

- Volume production, which one estimate suggests should be at least 300 units per hr, or a million units per year.

- Simple components that are easy to handle automatically, such as shafts or rods. Such parts are more easily fed and do not require complex feed mechanisms to orient them correctly.

In selecting fasteners for automatic assembly, the designer should try to standardize fastener size as much as possible. Standardization means fewer assembly stations and lower tooling and retooling costs.

Assembly elements

Automatic assembly components are available from various sources for installation of many types of standard fasteners such as screws, studs, pins, shafts and rivets. Special fasteners may require modification of standard assembly components and in some cases a complete design change.

In all cases, feeding and reliable orientation are generally the most difficult parts of the assembly process. If a fastener can be fed properly, it can be installed.

Assembly machines

Assembly machines are usually classified according to the path the work follows as it travels from station to station. The most common configurations are dial or rotary machines and in-line machines.

Dial assembly machines index the work on a round table from station to station. They are the type best suited to small and medium-size assemblies in the neighborhood of 500 to 3,600 units/hr, or higher. Assemblies with 30 or more components can be produced.

With dial machines, only relatively small and medium parts can be handled, accessibility is limited on these machines because of placement of work-stations around the table, and space is limited, making integration of manual and automatic stations difficult. Additional stations require a larger indexing dial.

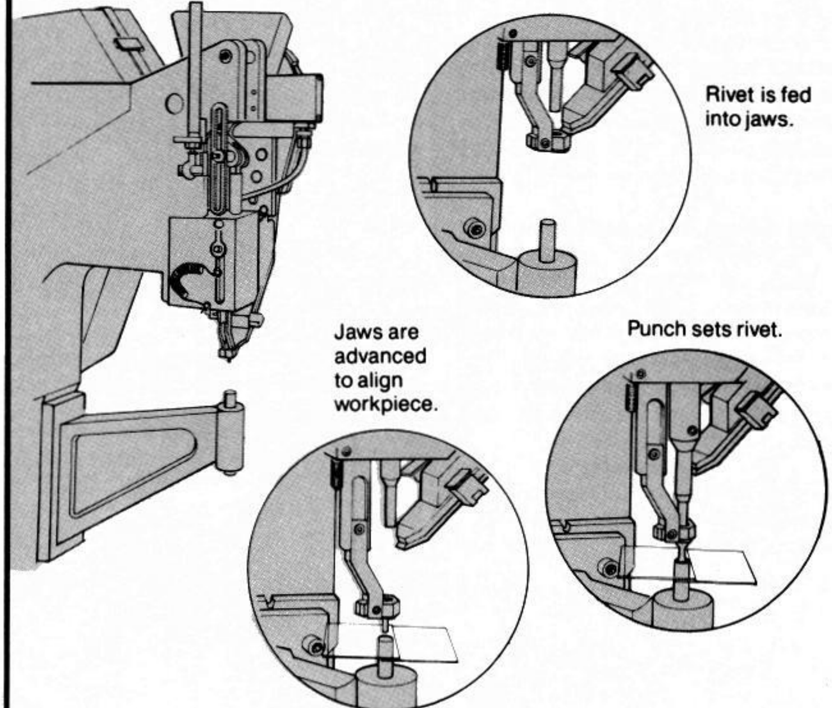
In-line machines are either a wrap-around or over and under type. In wrap- around machines the work moves in a rectangular path. In an over-and-under type, pallets or holding fixtures move horizontally in a straight path. Then, when empty, they return to the loading station on a conveyor running underneath the machine. Both types can take heavy parts.

Assemblies should have five to ten components. Up to 30 automatic stations with one or two manual operations are not uncommon. An assembly can also be fully automatic. In-line machines operate at rates of 500 to 1,800/hr.

Capacity of in-line machines is not restricted, and new stations can be added anywhere along the line. The machines have greater accessibility, which makes the in-

Moving jaws aid rivet placement

Rivet-setting machines usually do not allow operators to know exactly where a rivet will be placed because rivet-holding jaws must be positioned high above the workpiece to accept rivets from feed rails. A new slide mechanism preadvances jaws just above the workpiece to ensure that rivets are placed where required. The machine operator advances the jaws to their preset position to align the workpiece visually and then advances the punch to set the rivet. Milford Rivet & Machine Co., Milford, CT., reports that most single-spindle mechanical riveters can be retrofitted with the device.



Long-barreled screw gun speeds stress-plate installation

Tool for fastening stress plates through roofing insulation speeds installation by minimizing the number of steps normally required to do the job. The tool consists of a driver with a long barrel and a stress-plate holder. In operation, the installer simply feeds a screw into the side of the barrel and places a steel stress plate in the magnetized plate holder at the end of the barrel. The tool is then positioned so that it is in square with the work surface and the screw is driven through the plate and insulation into the steel roof decking. Fabco Fastening Systems, West Newton, PA., reports that the InsulFixx system allows a single installer to complete up to 2,000 fastenings per day.

sertion of a manual operation easier than with dial units.

Parts feeders

Basic to automatic assembly are part feeding and orientation:

Bowl feeders are probably the most common type of small-part feeding and orienting devices. Randomly oriented parts in a bowl move along a track that spirals upward along the inside wall of the bowl. As the parts move upward they are oriented and, at the top of the bowl, exit to a track. The aligned parts are then fed along this track using vibrators, conveyor belt, or gravity to the assembly station. Techniques used to align the parts while in the bowl include strike-off plates, narrow sections of track, auxiliary rails or hooks, and air blow-offs.

Barrel feeders are limited to parts with relatively simple geometry, such as cylinders. Parts are picked up in pockets in a tilted, rotating drum and carried to a stationary center post and track within the barrel. The parts are discharged at the top of the track and fed to the assembly station. Only properly oriented parts are able to enter the track.

Elevating feeders are similar to barrel feeders except that the barrel pick-up ring is replaced by an elevator belt. Tooling on the belt and the discharge track permits entry of only aligned parts to the track. Elevating feeders are suitable for parts that are too large for barrel feeders.

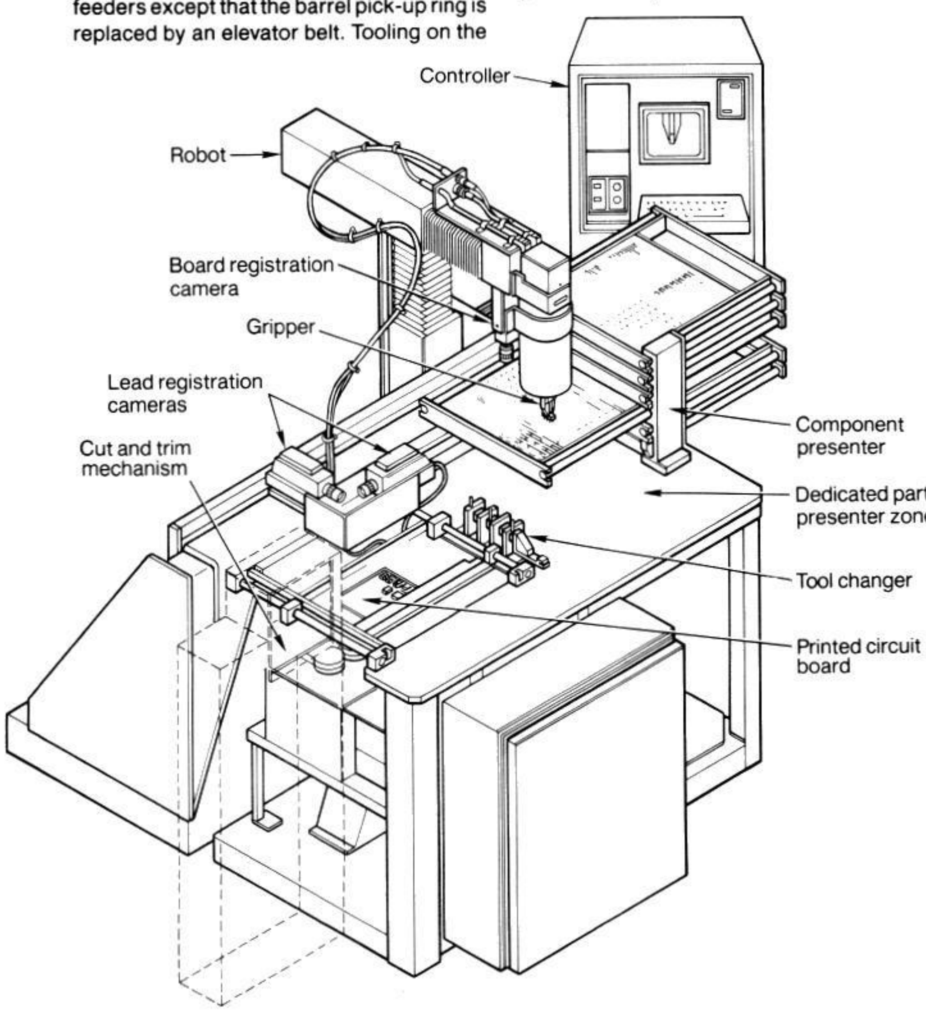
Parts magazines are best used when parts are difficult or expensive to orient automatically, or when their nature makes automatic feeding difficult (compression or spiral springs, for example). Parts are usually fed from the bottom of the magazine to the feed track by a shuttle. Magazines feed parts at a faster rate than can be done manually and provide a bridge between manual and automatic feeding.

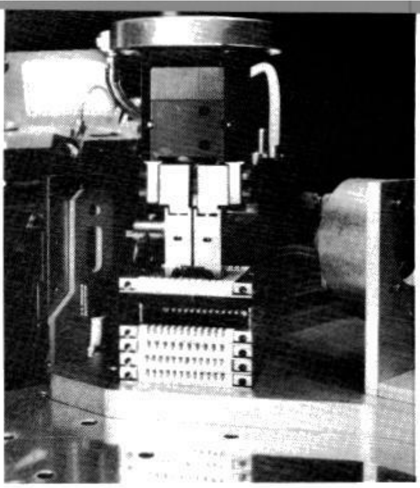
Blade feeders are used to feed to multiple tracks. Parts that are shaped to fit onto a blade. U-shaped clips, for example, are well suited for this type of feeder.

Assembly-line robots

Assembly robots began to become a distinct part of the robotic scene in the early 1980s. Lower cost microcomputers, electronic miniaturization, better quality motors, and controls all combined to give the newer robots capabilities and a price that made them appealing to manufacturers.

PCB assembly system offered by Automatix, Billerica, MA, functions as a stand-alone manufacturing unit. It includes a Cartesian robot, board sensing camera, several end effectors, parts presentation racks, component inspection cameras, lead trimmer, and complete control system.





Connector assembly uses Seiko RT 3000 robot to insert a series of wires. Only 12 seconds are required for the robot to select the proper wire, cut it, strip it, and secure it in its proper slot.

Of the huge potential for product assembly in U.S. industry, two categories are emerging most strongly. The first is in the electronics area: the assembly of PCBs, both insertion type and surface mount.

Second is mechanical component assembly. This is chiefly limited to complex parts made of many components and weighing only a few pounds, such as electric motors and gear reducers.

Another assembly area getting some attention from robots is "dispensing." This includes tasks such as adhesive application and forming seals and gaskets. These jobs generally require less precision than PCB or motor assembly.

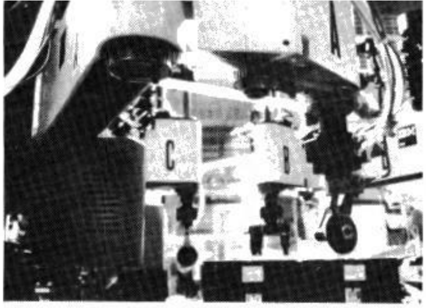
Operating credentials

Although practically any robot can be used for an assembly job, there are a limited number that have capabilities suitable for high precision or high volume assembly. Each robot's distinct characteristics and costs should be matched to project needs. Among the characteristics to consider are:

Work envelope: Where the robot can reach is essential and must include the workpiece area and all part supply mechanisms.

Payload: The maximum useful load a robot needs to be able to handle for assembly is given by most analysts as 10 kg. This will allow it to work with 85% of all manufactured parts. PCB board assembly tasks, of course, require much less payload capability.

Speed: Most assembly robots can reportedly serve assembly functions with



Scara robots in an IBM typewriter assembly facility each have four degrees of freedom.

speeds below 0.8 m/sec. Often because of the short distances traveled, an arm does not achieve its maximum speed. Therefore, speed considerations should take into account the robot's task.

Drives: Because of the speed and accuracy requirements, most assembly robots have most of their axes driven by either ac or dc servo motors. Pneumatic actuation is frequently used on the end effector and possibly the *z* axis.

Repeatability: Most robot manufacturers do not stress the ability of a robot to precisely reach a specific point. Most stress repeatability: how well it can repeat its travel to a specific point. Accuracy may be good in one plane of motion and poor in another, therefore overall accuracy is difficult to determine.

Coordinates: Most assembly robot arms are made to operate in Cartesian or cylindrical coordinates, or have an anthropomorphic (human-like) configuration. There are also scara (selective compliance robotic arm) robots. These arms have two joints that allow the arm to swing in the horizontal plane and plunge or *z* axis. The scara arm is favored for PCB manufacture because the arm can be positioned quickly and accurately over the board then move in the *z* axis to deliver the component.

The non-scara arms can usually reach more places than the scara arms. However, they are slower and less accurate because more joints and motions are involved. The non-scara arms are used more for assembly requiring complex maneuvers and access to all faces of the workpiece.

Programming and communication: Ease of programming, particularly on line programming, is a big factor. Although robots from different manufacturers cannot say much to each other, they can communicate basic triggering signals. Therefore the more RS232 ports available the better if complex systems are involved. Normally, more elaborate exchanges between robots such as reprogramming information is handled through a host.

Cleanliness: Lack of contamination is essential in any assembly operation and is especially important in electronics work. Operations must meet clean room standards. For example, a Class 100 room is to have no more than 100 0.5 micron particles per cu ft of air. (There is some question about the ability of existing instrumentation to accurately measure such small concentrations, but the standards exist nonetheless.)

Some robots are available with clean-room "packages." Others are designed specifically for clean rooms so that they generate a minimum of particulate matter from paint or wearing particles.

End effector: This piece of robot hardware must be selected after a review of the components to be carried. Compliance of the end effector will be based on how delicate the part handled is and any desired error compensation.

Grippers capable of working with several parts can speed assembly when part feeding and placement requirements are favorable. Changeable grippers for a single robot may be cost and time savers, if product configuration and production speed requirements allow.