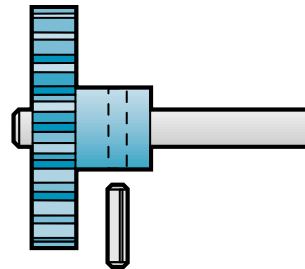


*Virtually every finished part requires some assembly: mechanical fasteners, welding, bonding, snap-fit joints, or other joining techniques. These methods and their design implications are discussed in this chapter.*

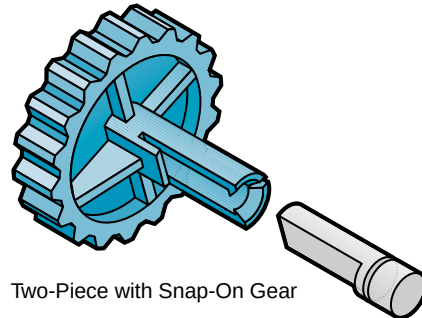
*Optimizing part assembly should begin with the concept stage and continue through product development and production. At each stage look for opportunities to simplify and improve the assembly. Consider consolidating parts, reducing fastener and assembly steps, improving automation, and selecting other assembly methods. Well-designed parts include features to ease assembly and assure correct positioning and orientation. In addition to cost and quality concerns, the optimization process should address disassembly for repair and recycling. Good communication and cooperation between the various design and engineering disciplines is essential. This chapter addresses assembly primarily as it relates to thermoplastic part design. For more specific information about various joining techniques and guidelines for their use with Bayer resins, please request a copy of *Joining Techniques and/or Snap-Fit Joints for Plastics* from your Bayer representative.*

Gear-to-Shaft Attachment Options

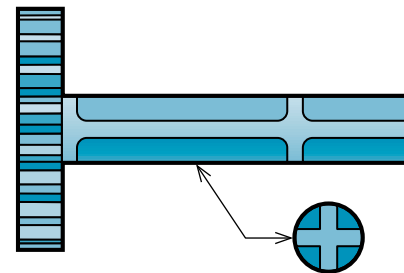
Figure 4-1



Three-Piece Assembly with Roll Pin



Two-Piece with Snap-On Gear

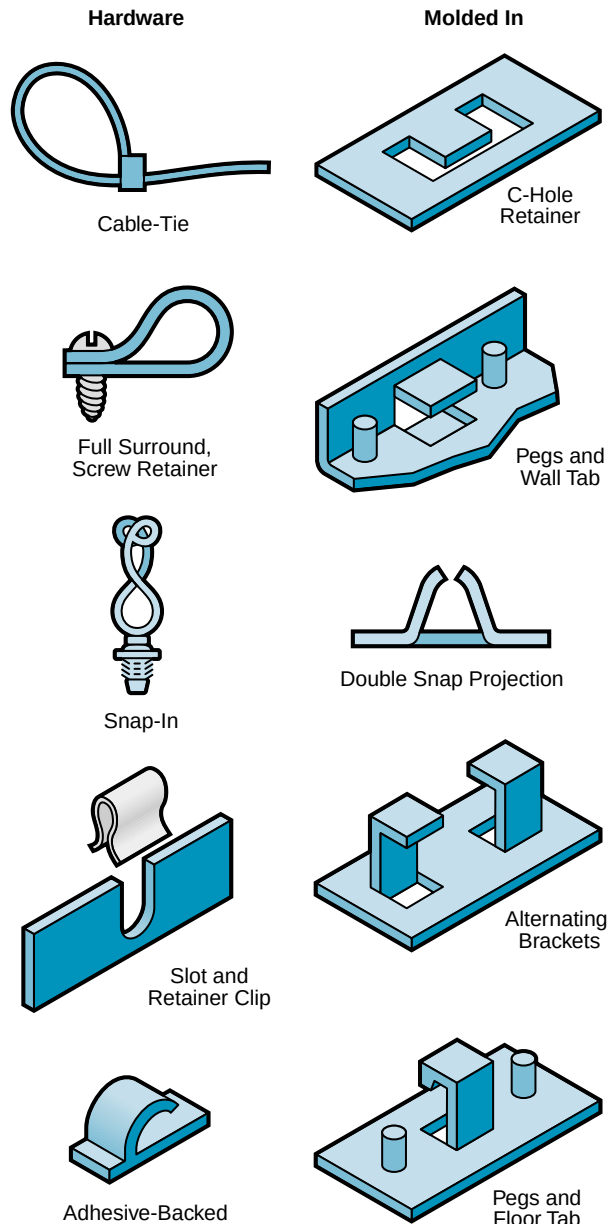


One-Piece Molded Gear and Shaft

### PART CONSOLIDATION

To lessen the need for fastening hardware and reduce the number of assembly operations, consider consolidating the number of parts in a given design. Closely scrutinize your total design for opportunities to combine function and reduce final assembly count. By way of example, figure 4-1

shows several options for attaching a gear to a shaft: a three-piece design, featuring a shaft, gear, and roll pin; a two-piece, snap-on gear design; and a one-piece shaft and gear design that needs no assembly. A variety of factors — including required strength, wear properties, and moldability — determine which of these design options is most feasible.



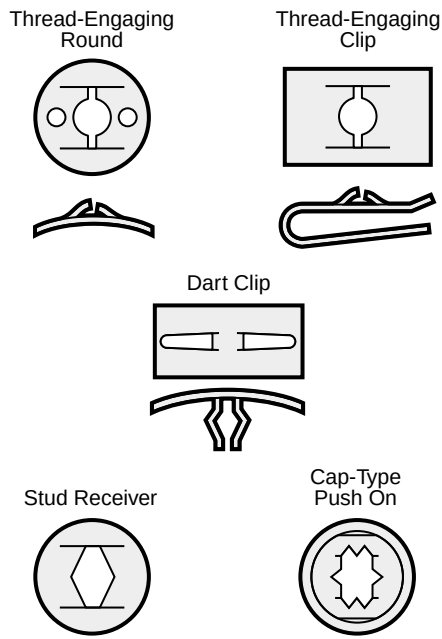
Molded-in features can replace cable-guide hardware.

Consider design options that eliminate or reduce the need for hardware. As an example, figure 4-2 shows several examples of molded-in alternatives to cable-guide hardware. Usually, the cost savings in hardware and assembly far exceed the added costs of mold modification and materials.

### MECHANICAL FASTENERS

Mechanical fasteners — screws, bolts, rivets, and others — and their installation often represent a large portion of total assembly costs. They also add to the cost of dismantling products for repair or recycling. To reduce costs, consider replacing mechanical fasteners with snap-fit joints, molded-in hinges, latches, and other similar design features. Use interlocking and/or nesting features to reduce the number of screws needed.

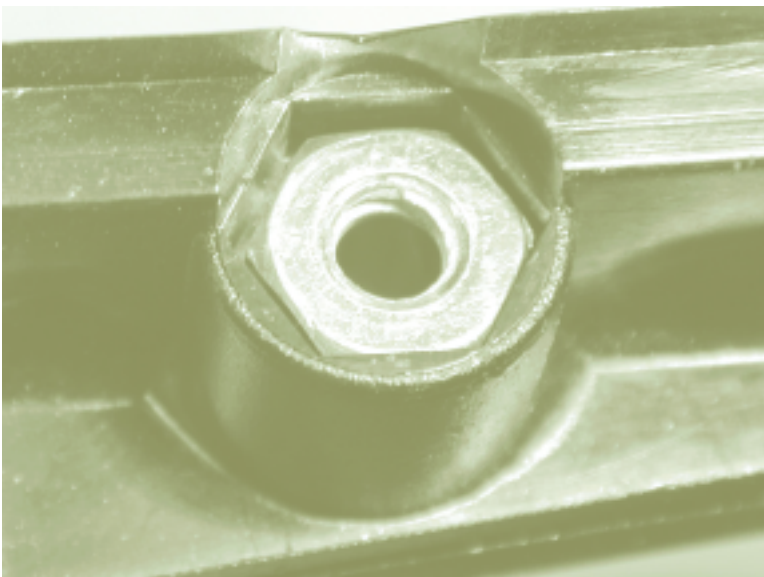
When you must use fasteners, choose from the multitude of inexpensive, off-the-shelf varieties to lower costs. Additionally, many specialty fasteners for almost any type of application are available such as the spring-clip fasteners in figure 4-3. Avoid expensive, custom, or low-production fasteners, unless the performance advantage justifies the additional costs. Whenever possible, standardize fasteners to simplify inventory control and automation processes, as well as reduce unit cost.

**Spring Clips****Figure 4-3**

Inexpensive spring-clip fasteners are available for many applications.

Consider simplifying installation. For example, use hex holes to captivate nuts during assembly (see figure 4-4). Other ideas to consider include:

- Select good-quality screws with shaft-to-head-diameter ratios and head styles suited to automatic feed in assembly equipment;
- Avoid handling loose washers — use screws with washers affixed under the head;
- Use self-tapping screws to avoid a secondary tapping step;
- Use metal threaded inserts for screw connections subjected to frequent disassembly; and
- Consult Bayer's *Joining Techniques* for more information on mechanical fastening.

**Hex Hole****Figure 4-4**

Hex holes captivate nuts during assembly.

### **SNAP-FIT JOINTS**

Both economical and versatile, snap joints can eliminate fastening hardware, as well as reduce assembly and disassembly costs in a wide range of applications. Although they vary in appearance, all snap-fit joints rely upon the brief deflection of a flexible member to interlock a depression or undercut with a protrusion on a mating part. Varieties include cantilever snap-arms, and

torsional or annular snap-joint styles (see figure 4-5). The shape of the undercut determines if the joint can be separated later. Snap-fit designs with an angled undercut contact can be disassembled without first deflecting the snap feature to disengage the connection.

If designed properly, snap-fit joints can secure parts of assemblies, such as solenoids and switches, replacing more-expensive screws (see figure 4-6). Special snap-joint designs can also act as latches for access doors and panels. Multiple snap arms or a combination of snap arms and rigid undercuts can often secure covers and panels (see figure 4-7). Rounded lids — such as on film canisters or food-storage containers — use annular snap-fit designs for continuous attachment and a good seal.

Snap-fit joints provide both secure attachment and easy disconnection of electrical connectors. They also facilitate quick and easy detachment of electrical components for repair and recycling. Some rules of thumb for designing snap-fit joints include:

- Design parts so that the flexure during snapping does not exceed the allowable strain limit of the material;
- Design parts so that the flexing member of the snap-fit joint returns to a relaxed, undeflected position after assembly;

- Avoid sharp corners in high-stress areas, such as at the base of a cantilever arm;

**Table 4-1** Permissible Short-Term Strain Limits at 23°C (73°F)

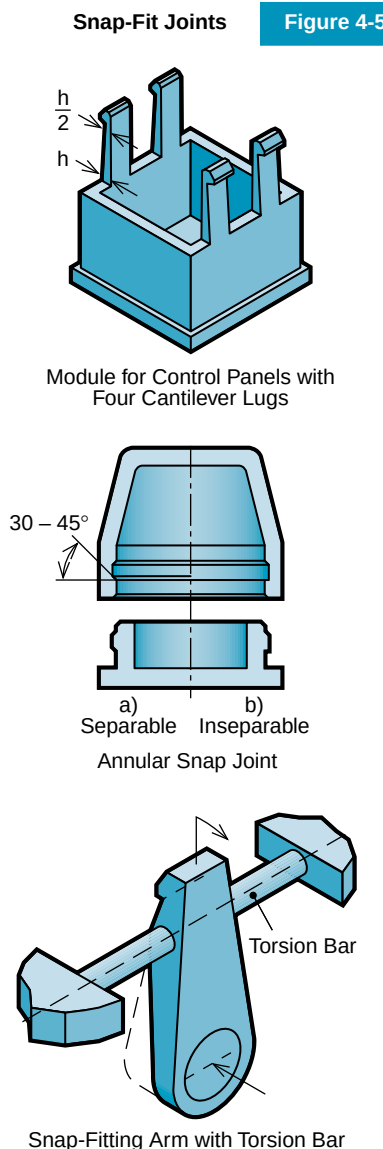
## Unreinforced

|                   |                  |              |
|-------------------|------------------|--------------|
| <b>Apec</b>       | High Heat PC     | 4.0%         |
| <b>Bayblend</b>   | PC/ABS           | 2.5%         |
| <b>Centrex</b>    | ASA              | 1.9%         |
| <b>Durethan</b>   | PA cond.<br>dry  | 6.0%<br>4.0% |
| <b>Lustran</b>    | ABS              | 1.8%         |
| <b>Makroblend</b> | Polycarb. Blends | 3.5%         |
| <b>Makrolon</b>   | PC               | 4.0%         |
| <b>Triax</b>      | PA/ABS           | 3.4%         |

**Glass-Fiber-Reinforced (% Glass)**

|                       |              |              |
|-----------------------|--------------|--------------|
| <b>Makrolon (10%)</b> | PC           | 2.2%         |
| <b>Triax (15%)</b>    | PA/ABS       | 2.2%         |
| <b>Makrolon (20%)</b> | PC           | 2.0%         |
| <b>Durethan (30%)</b> | PA cond. dry | 2.0%<br>1.5% |

General guide data for the allowable short-term strain for snap joints (single joining operation); for frequent separation and rejoining, use about 60% of these values.



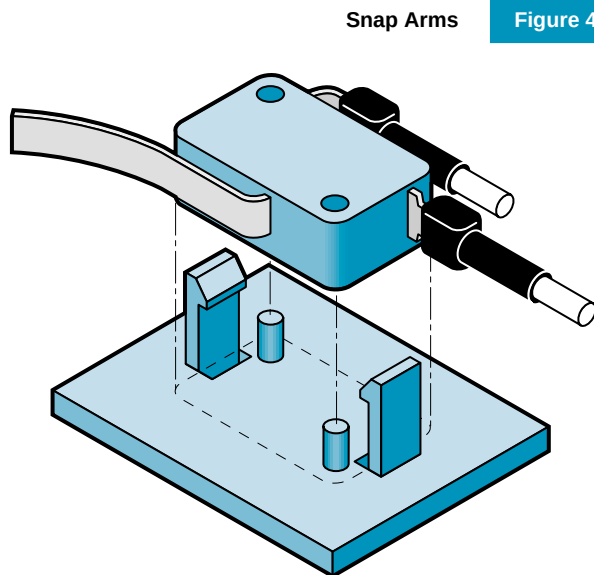
### Varieties of snap-joint types.

- Round corners to a minimum radius of 0.015 inch to reduce stress concentrations; and
- Avoid excessively large radii that could lead to sinks or voids.

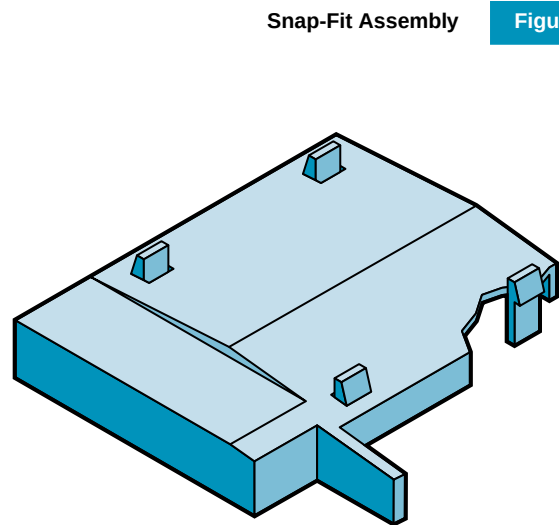
Table 4-1 shows the permissible strain limits for various Bayer materials. The Bayer publication *Snap-Fit Joints for Plastics* explains how to calculate strain, permissible deflection, and assembly forces for various types of snap-fit joints. Consult this publication for additional information on snap-fit joint design.

In addition to meeting functional requirements, snap-fit joints must conform to standard, part-design guidelines, including:

- Avoid thin-wall sections that could lead to filling problems;
- As with ribs, make snap arms that project perpendicular to the part surface no more than 1/2 to 2/3 of the thickness of the part wall; and
- Draft snap-arms as you would ribs to ease release from the mold.



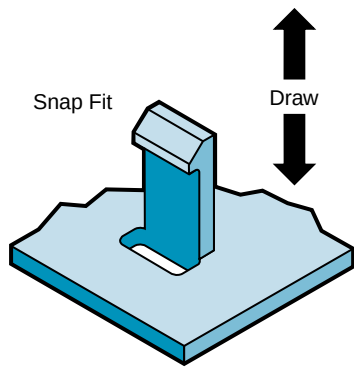
Positioning posts and snap arms eliminate screws and speed assembly.



Multiple snap arms secure cover in this assembly.

Snap Arm

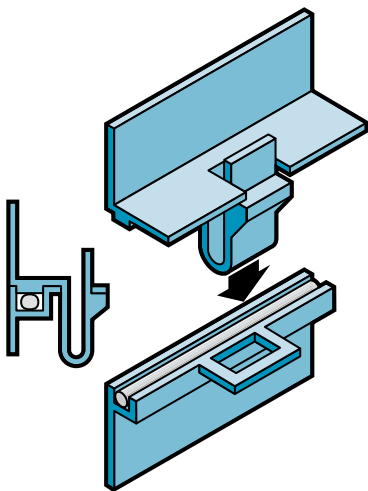
Figure 4-8



Snap-fit hook molded through hole to form undercut.

Thumb Tab

Figure 4-9



Special "U"-shaped snap latch with thumb tab.

Consider molding issues early in part design. To lower mold-construction and -maintenance costs, design simple, straight-draw, snap-fit joints (see figure 4-8), rather than ones that need slides in the mold. In some designs, the proximity of the snap-fit joint to other part or mold features does not leave enough room for a slide mechanism. Annular designs can be particularly difficult to mold. Some need collapsible cores or ejector sleeves, which can be problematic and difficult to maintain. Consult an experienced mold engineer before specifying any design that uses slides or other mechanisms to clear or eject undercuts.

The molding process offers the versatility to customize snap-fit designs for each application. For example, snap arms on frequently used doors or access panels could have finger tabs added for easier opening (see figure 4-9). Limited-access doors could have hidden snap-fit joints or require special tools. Some applications may require modifications in the snap arm to prevent excessive material strain during deflection. Consider lengthening the snap arm, reducing the undercut, or tapering the arm thickness in these situations (see figure 4-10).

Snap-fit features intended for automated assembly should join with a simple, one-direction motion, rather than a tilt-and-push or slide-and-push motion. The opposite may be true for hand-assembled components. Avoid designs that require more than two hands to engage or release a snap-fit joint.

## WELDING AND BONDING

Welding and bonding techniques offer a wide variety of excellent joining and assembly options. In many applications, they provide the only viable methods of assembly. Both of these methods provide permanent bonds. Avoid welding and bonding when using materials that will have to be separated for recycling or repair, or when less-expensive joining methods suffice. When you must weld or bond, minimize the mix of techniques and equipment used.

This section deals with the broader aspects of welding and bonding and their effects on part and assembly design. For more specific information on welding and bonding, request a copy of *Joining Techniques* from your Bayer representative.

Common welding methods, including ultrasonic, vibration, hot plate, spin, and induction, each have specific advantages, as well as design and equipment requirements. These are discussed below.

#### *Ultrasonic Welding*

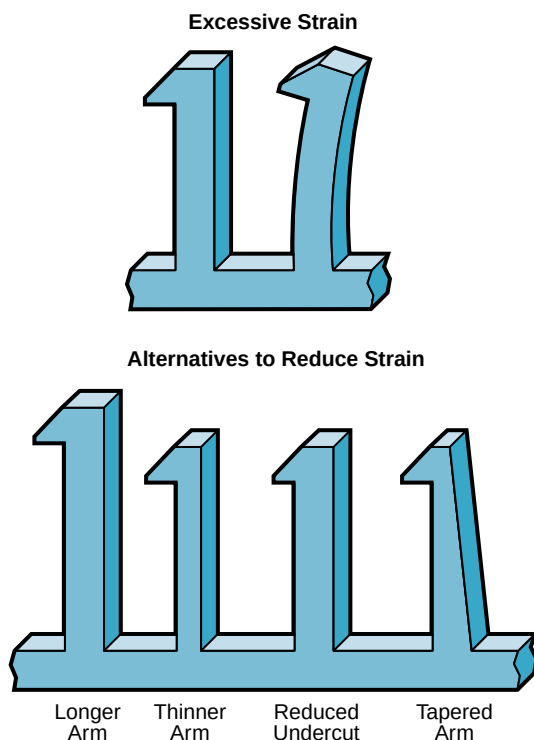
Ultrasonic welding, one of the most widely used joining techniques, is an excellent bonding method for thermoplastics. It makes permanent, aesthetically pleasing joints, at relatively high rates of speed. In this welding technique, an ultrasonic assembly unit generates mechanical vibratory energy at ultrasonic frequencies. The ultrasonic vibrational energy is transmitted through one of the mating parts to the

joint area where frictional heating melts the plastic and forms the weld. When designing parts that will be ultrasonically welded, consider the following:

- For strong, consistent welds, ultrasonic joints need properly designed energy directors (see figure 4-11) or shear weld features;
- The equipment size and welding-horn design limitations determine the size and number of ultrasonic welds per operation;

**Snap Arms**

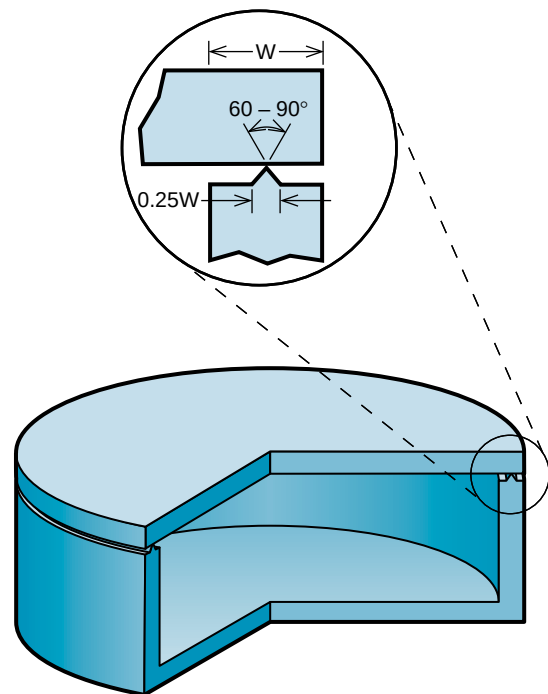
**Figure 4-10**



Short, thick snap arms with large undercuts can experience excessive strain during deflection. Consider lengthening or thinning the arm, reducing the undercut or tapering the arm to reduce strain.

**Energy Director**

**Figure 4-11**



Typical energy-director design for Bayer thermoplastics.

- Mating materials must be compatible and rigid enough to transmit the ultrasonic energy to the joint area; and
- Stray welding energy can damage free-standing features and delicate components. Consult your welding experts for help in resolving this problem.

For more specific information on ultrasonic welding, request a copy of *Joining Techniques* from your Bayer representative.

#### *Vibration and Hot-Plate Welding*

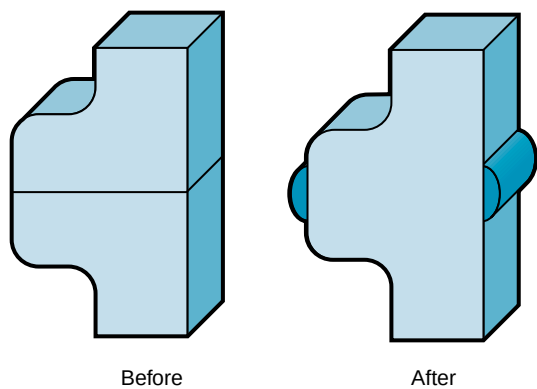
To form continuous welds over large areas — particularly those too large for conventional ultrasonic welding — consider vibration or hot-plate welding. A friction-welding technique, vibration welding requires wide joint surfaces to accommodate the sliding vibration.

To avoid dampening the vibration, part geometry must rigidly support the mating joint surfaces. In this process, one part remains stationary, while the second vibrates on the joint plane, generating heat. When the joint interface reaches a melted state, the parts are aligned and clamped until the bond has set.

For permanent, non-cosmetic welds along a single plane, hot-plate welding offers an economical joining method. In this joining method, a heated platen contacts two plastic parts until the joint area melts slightly. The platen retracts, and the parts are then pressed together until the bond sets.

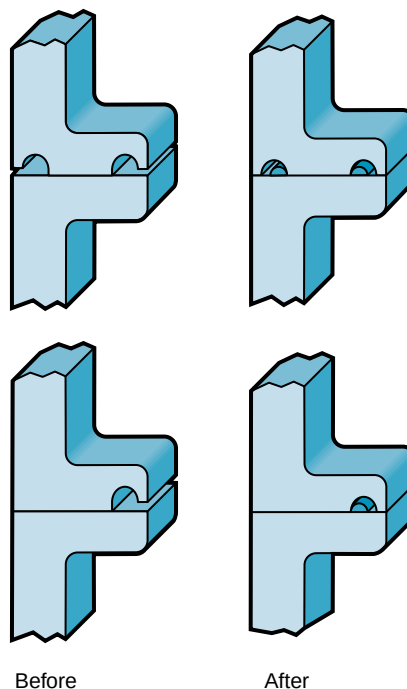
Both techniques can produce flash or a bead along the joint when applied to simple butt-weld configurations (see figure 4-12). Consider joint designs with flash traps (see figure 4-13) for applications requiring flash-free joints.

**Figure 4-12** Welding Flash



Butt-joint welds result in flash along the joint.

**Figure 4-13** Flash Traps



Variations with flash traps.

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### *Spin Welding*

Spin welding is used extensively to weld circular parts with continuous joints. Spin welding relies on frictional heat generated between mating parts, one spinning and one stationary, to melt plastic in a circular joint. After the friction melts a sufficient amount of plastic in the joint, the rotating stops and pressure increases to distribute melted material and complete the bonding process.

Parts designed for spin welding often have an alignment feature, such as a tongue and groove, to index the parts and make a uniform bearing surface. Joints for spin welding can also include flash traps to avoid visible welding flash.

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### *Solvent and Adhesive Bonding*

Probably the most versatile joining methods, solvent and adhesive bonding produce permanent bonds. These techniques place few restrictions on the part design. Solvent bonding joins one plastic to itself or another plastic by softening small areas on the joining surfaces with a volatile solvent. Adhesives are one-part or two-part “glues” that adhere to mating surfaces and cure to form the bond.

Solvent bonding limits your choice of materials to plastics for which there is a suitable solvent. When bonding dissimilar materials, the same solvent



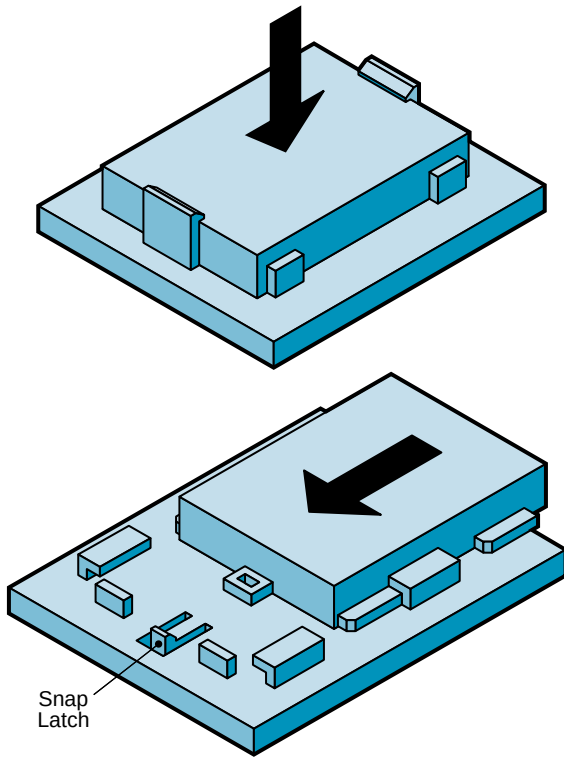
must work on both materials. If your part will be made of polycarbonate resin, allow for vapor dispersion after bonding. Trapped solvent vapors can attack and damage polycarbonate resins.

Adhesive bonding offers more versatility for bonding different types of plastics together and also dissimilar materials, such as plastics to metal, plastics to glass, fabric to plastic, etc. The Bayer brochure *Joining Techniques* lists various adhesives and their suitability for use with different Bayer resin families.

When selecting an adhesive, consider curing time and cost as well as special adhesive system requirements. UV-cured adhesives, for instance, work best with transparent plastic parts. The part design must accommodate direct-line-of-sight access from the UV source to the bond area or the bond edge.

Retention Features

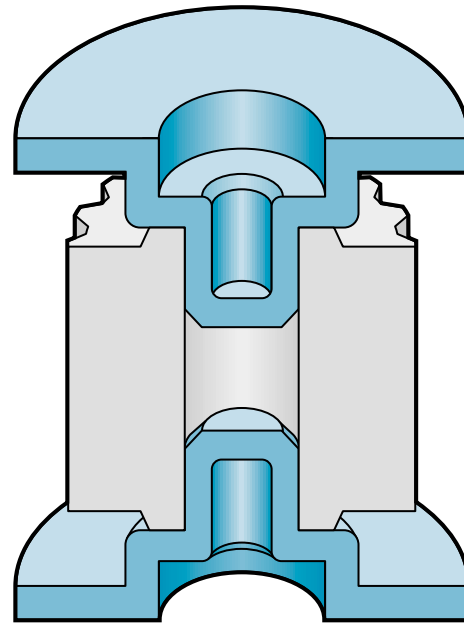
Figure 4-14



Molded-in assembly features can captivate and retain components without hardware.

Assembly Features

Figure 4-15



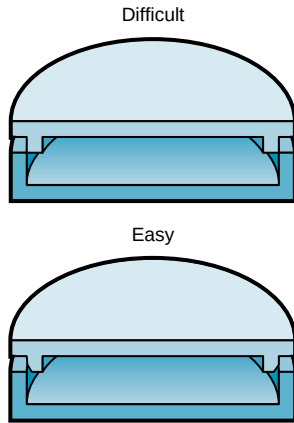
Parts can be captivated between halves of an assembly as in this illustration of a gear held in place between axle posts.

## RETENTION FEATURES

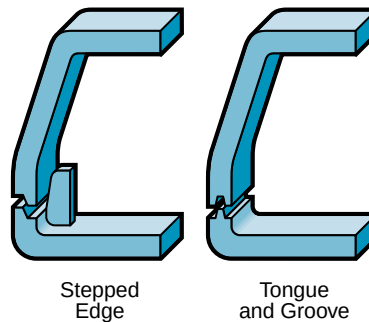
The molding process offers the freedom to custom-design features to locate and retain components during assembly. Components can nest between ribs or slide into molded-in retainers for assembly without hardware (see figure 4-14). In some products, halves of the assembly can captivate components without additional attachment (see figure 4-15). This joining method permits efficient assembly and simplifies dismantling for repairs or recycling.

## ALIGNMENT FEATURES

To help in assembly, consider designing your part with alignment features. Parts must assemble easily and efficiently, despite minor misalignments. Parts with sharp leading edges can snag or catch during assembly, requiring more time and effort. Chamfers added to either or both leading edges quickly align mating features, reducing the positioning accuracy needed for assembly (see figure 4-16).

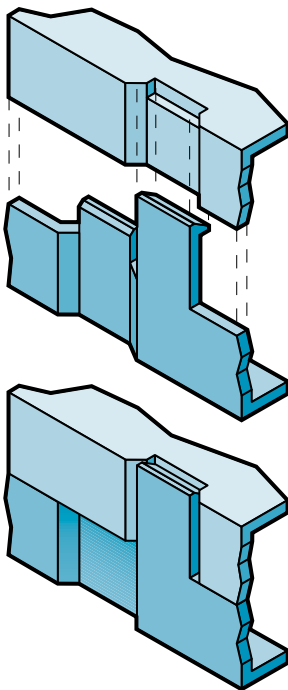
**Lead-In Angles****Figure 4-16**

Lead-in angles on the lid in the lower assembly help to align the lid with the base and ease assembly.

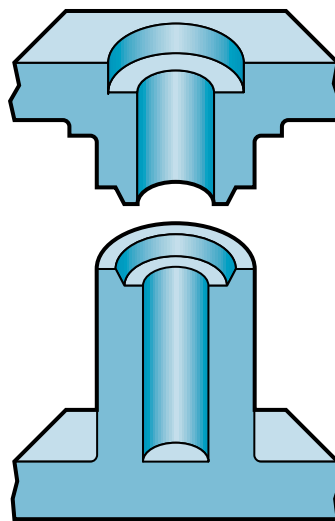
**Edge Alignment****Figure 4-17**

Tongue-and-groove or stepped features ensure proper edge alignment.

Housing or enclosure sidewalls can bow during molding or deflect under loading, resulting in poor alignment along mating edges. When appearance is important, consider designing an interlocking edge to correct for this bowing (see figure 4-17). On thin sidewalls, full tongue-and-groove designs split the sidewall thickness into two thin sections. This design may lead to molding problems and lack the required strength. A somewhat better design, the stepped edge, can have high molding stresses and a gloss difference at the thickness transition. Rounding or chamfering the transition corner often improves this condition. The stepped-edge design supports the wall in just one direction. Adding a protruding rib to support the inside surface locks the walls in two directions and provides better alignment.

**Alignment Fingers****Figure 4-18**

Bypass fingers ensure proper alignment of sidewalls while maintaining uniform wall thickness.

**Boss Alignment****Figure 4-19**

Existing design elements can often be modified to provide positive part alignment as in the angled lead-ins added to these mating screw bosses.

When aesthetics are less important, choose a more-robust, interlocking design for aligning sidewalls. A variety of easily molded design options using interlocking alignment fingers can align and secure the sidewalls while maintaining uniform wall thickness (see figure 4-18). Other simple options for aligning mating parts include post-in-hole and boss-alignment features (see figure 4-19). The astute designer often can modify existing part-design features for positioning and alignment with little added part or mold cost.

## ORIENTATION

Adding orienting features to molded parts can simplify assembly, reduce costs, and prevent assembly errors. When possible, incorporate features that prevent assembly unless components are oriented correctly. Otherwise, clearly indicate correct orientation on the mating parts (see figure 4-20). Symmetry simplifies assembly. Often parts need only minor modifications to increase symmetry and allow orientation in more than one direction (see figure 4-21).

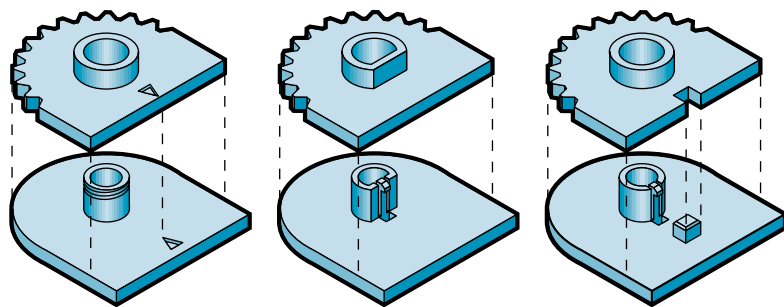
## EXPANSION DIFFERENCES

Plastic parts are often attached to components made of materials with much different coefficients of linear thermal expansion (CLTE). If your part will contain different materials, design for CLTE differences. For instance, a plastic part tightly attached to a metal component can bow between attachment points when exposed to elevated temperatures (see figure 4-22). Designing the plastic section with slotted holes provides a sliding fit to accommodate dissimilar levels of expansion. You may need to make similar design adjustments when joining plastic parts to parts made of certain polyamides and other plastics that swell significantly as they absorb moisture.

## TOLERANCES

If all components of an assembly could be produced and joined with perfect repeatability and accuracy, the task of assigning tolerances would be simple. However, each manufacturing step introduces its own variability and with it, potential tolerance problems. For instance, molded-plastic part dimensions vary with processing fluctuations. Stamping and machining create part-to-part differences in metal components. Assembly steps such as positioning, guiding, indexing, fixturing, and welding present additional sources of variability. When developing part tolerances, consider the following:

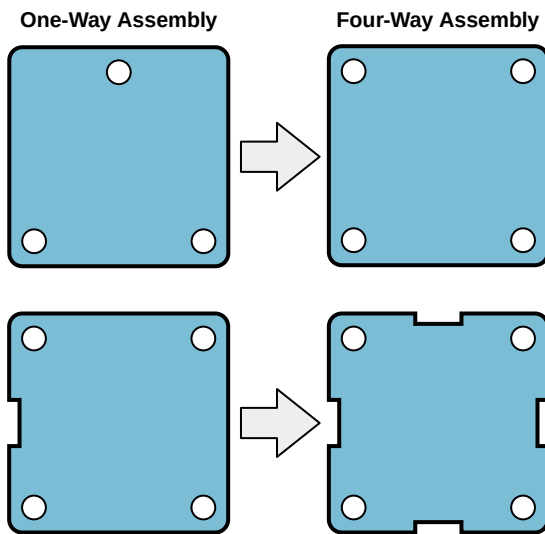
**Figure 4-20** Orientation Features



To ensure proper orientation during assembly, add features that either mark the correct position or prevent assembly of misaligned components.

Orientation Symmetry

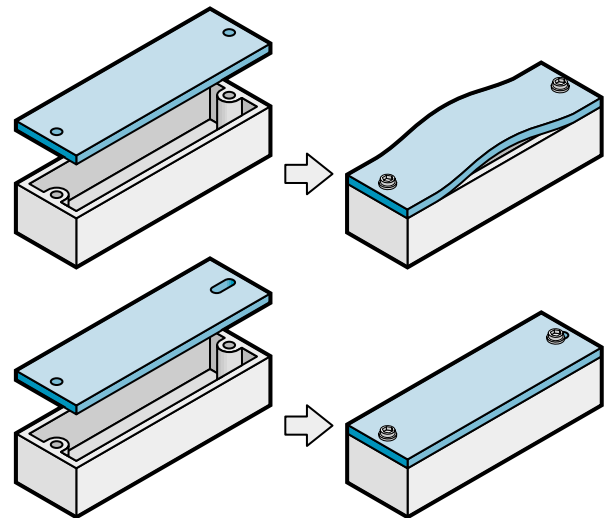
Figure 4-21



Simple modifications can often increase symmetry and simplify assembly.

Thermal Expansion

Figure 4-22



The slotted hole and sliding attachment at one end of the plastic cover in the lower assembly enable it to accommodate the thermal expansion difference with the metal base.

- Avoid specifying arbitrarily tight tolerances to components and the assembly process, as it can add needlessly to costs;
- Accommodate part and process variability in your design;
- Include design features such as slotted holes, alignment features, and angled lead-ins to lessen the need for tight tolerances;

- Take advantage of the ability of the injection-molding process to mold small features with excellent repeatability; and
- Avoid tight tolerances on long dimensions and on features prone to warpage or distortion.

Exercise discretion when assigning available tolerances between the components and assembly processes. Give the tightest tolerances to the part, feature, or process that adds the least cost to the entire process. It may be more economical to loosen the tolerance on the plastic component and tighten the tolerance on the assembly procedure or mating components. Consider all the sources of variability and optimize tolerances for the lowest overall cost. See the mold design chapter for more information on tolerances.