BRANSON

Ultrasonic Plastic Joining

Part Design for Ultrasonic Welding

Ultrasonic energy has been used to join thermoplastics for over 35 years. Ultrasonic welding of thermoplastic materials is by far the most common form of ultrasonic assembly, and is used extensively in all major industries including: automotive, appliance, electronic, toy, packaging, textile, and medical. It offers advantages in speed, economy, and efficiency, and is frequently chosen when parts are too complex or expensive to be molded in one piece.

This bulletin provides guidelines to aid the designer during the initial concept stage of a new product design, ensuring optimum production results. The dimensions given in the designs should be used as *guidelines only,* since the specifics of your application may require variations. If you have questions or need assistance in designing your parts, contact your local Branson representative, Branson Regional Technical Center, or the Application Laboratory at Branson's headquarters in Danbury, Connecticut.

Primary Factors Influencing Joint Design

All of the following basic questions must be answered prior to the design stage to gain a total understanding of what the weld joint must do:

- What type of material(s) is to be used?
- What is the overall part size and configuration?
- What are the final requirements of the part?
  - Is a structural bond desired? If so, what loads does it need to resist?
  - Is a hermetic seal required? If so, to what pressure?
  - Does the assembly require a visually attractive appearance?
  - Is flash or particulate objectionable inside and/or outside?
  - Any other requirements?

Three Major Joint Design Characteristics

In order to obtain acceptable, repeatable welded joints, three general design guidelines must be followed:

1. **The initial contact area between the mating surfaces should be small** to concentrate and decrease the total energy (and thus the time) needed to start and complete melting. Minimizing the time the vibrating horn remains in contact with the part also reduces the potential for scuffing, and since less material is moved, less flash is generated.
2. **A means for aligning** the mating parts should be provided. Features such as pins and sockets, steps, or tongues and grooves, should be used for alignment rather than the vibrating horn and/or fixture, to ensure proper, repeatable alignment and to avoid marking.
3. **Horn contact directly over the joint area** should be accommodated in order to transmit the mechanical energy to the joint area, while reducing the propensity for part marking.

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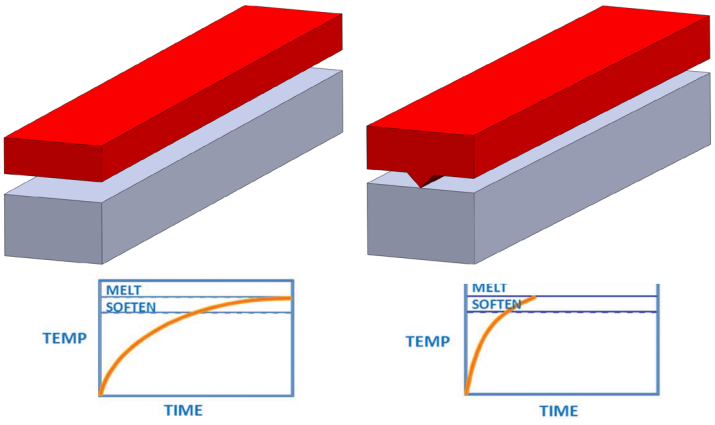
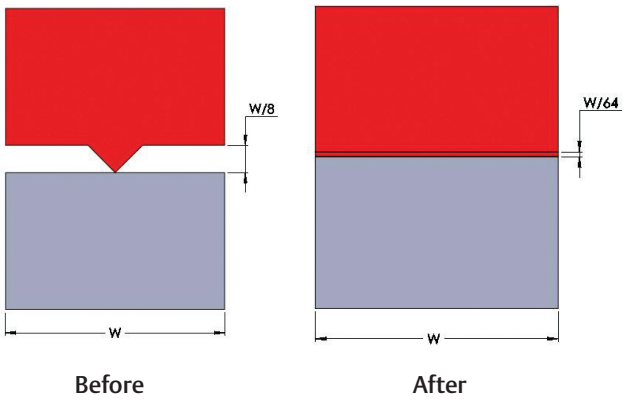
Part Design Ultrasonic Welding



Butt Joint | Butt Joint with Energy Director

Figure 1. Time-Temperature Curves: Butt Joint vs. Energy Director Design



Before | After

Figure 2. Basic Energy Director Design Formula

Two Major Types of Joint Design

There are two major types of joint design: the **energy director** and the **shear joint.** All other joint variations can be classified under these general categories or as hybrids combining aspects of both.

Energy Director — The energy director is typically a raised triangular bead of material molded on one of the joint surfaces. The primary function of the energy director is to concentrate the energy to rapidly initiate the softening and melting of the joining surface. The diagrams in Figure 1 show time-temperature curves for a butt joint and the more ideal joint incorporating an energy director. The energy director permits rapid welding while achieving maximum strength; material within the director generally flows throughout the joint area. The energy director is the most commonly-used design for amorphous materials, although it is also used for semi-crystalline materials.

Butt Joint with Energy Director —The basic design formula for the energy director design is illustrated in Figure 2. It is very important to remember that the size and location of the energy director on the joint interface are dependent upon:

- Material(s).
- Requirements of the application.
- Part size.

The peak of the energy director should be as sharp as possible; energy directors that are round or flat at their peak will not flow as efficiently.

In the case of semi-crystalline resins (e.g., acetal, nylon) with an energy director, the maximum joint strength is generally obtained only from the width of the base of the energy director.

Although the energy director can be located on either half of the part, it is generally included on the part contacted by the horn. In special situations (as in combinations of different materials), the general practice is to place the energy director on the part with the material that has the highest melt temperature and stiffness.

The energy director design requires a means of alignment such as pins and sockets, aligning ribs, or tongue and groove designs. Ejector pins should not be placed in the weld area.

***NOTE:** Typically a 90° included angle is used for amorphous resins, while a 60° included angle is used for semi-crystalline resins. The included angle may vary depending on materials, fillers, part geometry, or requirements. For recommendations regarding your specific application, please contact your local sales engineer or regional office.

Variations of the Energy Director Joint

The basic energy director design can be incorporated into joint configurations other than the butt joint to gain additional benefits. Examples of joint design variations utilizing an energy director include the following alternatives:

Step Joint — The step joint is used for alignment and for applications where excess melt or flash on one exposed surface is objectionable (Figure 3). Note that 0.005 to 0.020 inch (0.127 – 0.508 mm) has been added to the gap surrounding the perimeter of the part. This adds a feature called a “witness line” to the design.

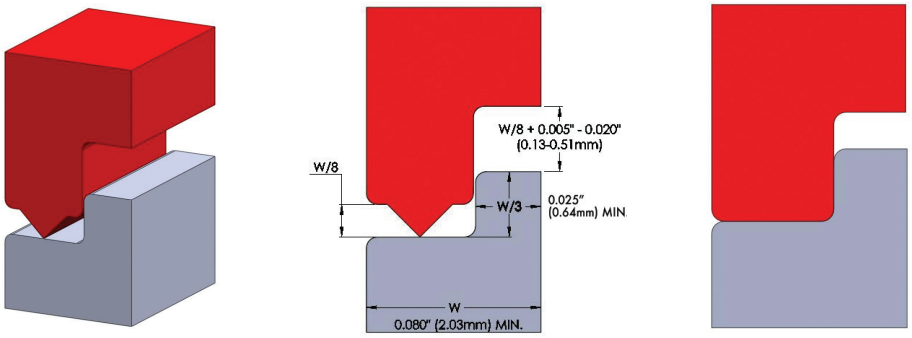


Figure 3. Step Joint

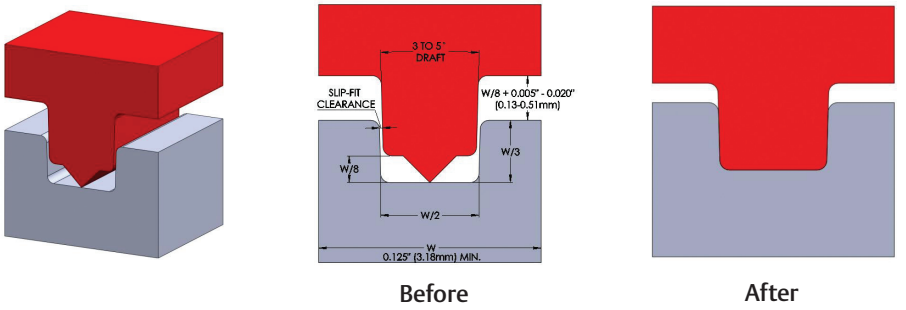


Figure 4. Tongue and Groove Joint Design

Branson/Moldtech Texture Designation	Pattern Depth
Branson 300/11040	0.003”
Branson 450/11050	0.0045”
Branson 600/11050-6	0.006”

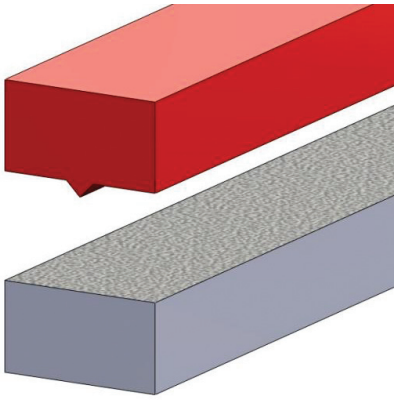


Figure 5. Textured Surface

**This design is covered by Branson Patent No. 4,618,516. License to utilize this design is granted via the purchase of Branson equipment.

When welding is completed, the witness line around the periphery of the part, will create a more appealing appearance, since part-to-part variations will be less noticeable. If the gap were completely closed, it is likely that flash would be formed in some outside areas, with slight gaps in others; whereas with the witness line, minor variations in the parts are less likely to be noticed.

The design of the energy director uses the same basic design thought process used in the butt joint energy director (i.e., material, requirements, part size). Note that a minimum wall thickness of 0.080 inch (2.00 mm) is recommended for this design.

Tongue and Groove — This joint design helps to contain flash, both internally and externally, while providing alignment between the parts (Figure 4). Containment of the material within the groove aids in the achievement of a hermetic seal. The need to maintain clearance on both sides of the tongue, however, makes this more difficult to mold.

Textured Surface** — This feature is exclusively used in conjunction with an energy director. Molding a textured surface on the mating part tends to improve the overall weld quality and strength by enhancing frictional characteristics and melt control (Figure 5).

Usually the texture is 0.003 to 0.006 inch deep (0.076 to 0.152 mm), and is varied based on the height of the energy director. In most cases, the advantages include increased weld strength, reduced flash or particulate, reduced weld times, or lower amplitude requirements. (Branson TechnoLog TL-4 provides details on this concept.)

Criss-Cross —This design incorporates energy directors on both mating sections that are perpendicular to each other, and provides minimum initial contact at the interface while

allowing a potentially larger volume of material involvement. This can result in increased strength in the weld (Figure 6). Each energy director should be dimensioned at approximately 60% of the size that would be used in a standard single energy director design, with an included angle of 60° versus the standard 90°.

If an air- or liquid-tight seal is required, it is recommended that the corresponding energy directors be continuous, like a saw tooth (Figure 7). The corresponding saw-tooth energy directors must be located on the part that will be contacted by the horn. Note that this design generates a very high material flow; therefore, containing flash should be addressed in part design (e.g., use a tongue and groove or step design).

In order to achieve a hermetic seal with this design, it is important that there is no gap between each of the energy directors in the saw tooth. For round parts, the energy director should be designed as shown on the Figure 8, with height and included angle according to the desired dimension on the ID, with the included angle of the energy director increased on the OD to close the gap between the bases of the energy directors.

Energy Director Perpendicular to the Wall — Used to gain resistance to peeling forces and to reduce flash (Figure 9). This design should be used when only a structural seal is required.

Interrupted — Used to reduce the overall area and subsequent energy or power level required, or to minimize part marking. Use only where structural (non-hermetic) seals are needed (Figure 10).

Chisel Energy Director — Typically used when nominal wall thickness is 0.060 inch (1.524 mm) or less (Figure 11). If a standard energy director is used, it will be too small (less

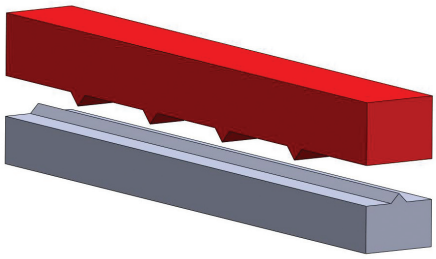


Figure 6. Criss-Cross Energy Director

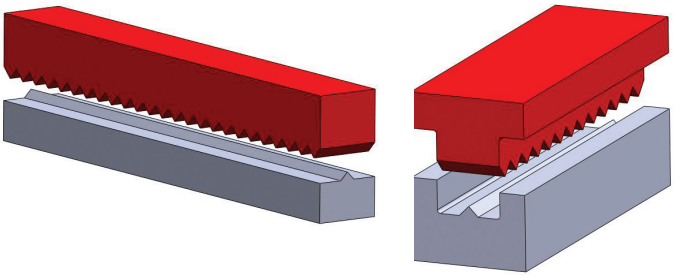


Figure 7. Criss-Cross Design for Air- or Liquid-Tight Seals

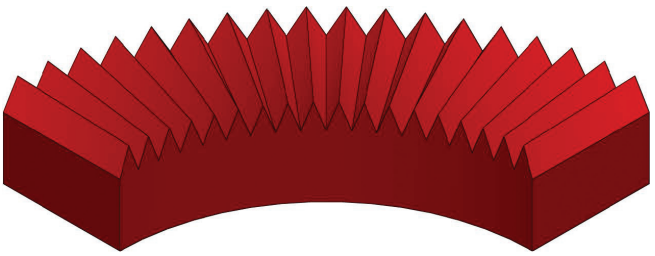


Figure 8. Criss-Cross Design on round parts

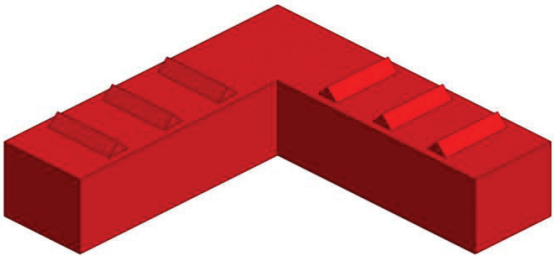


Figure 9. Energy Director Perpendicular to the Wall

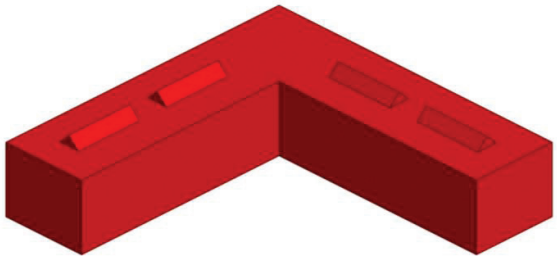
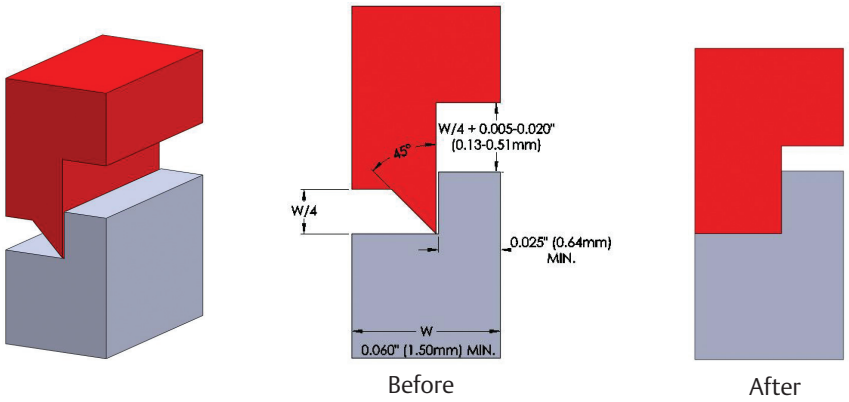


Figure 10. Interrupted Energy Director



Before After

Figure 11. Chisel Energy Director

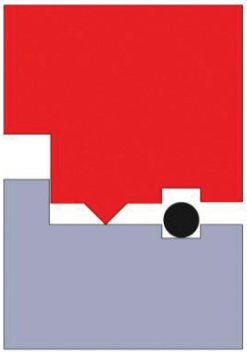
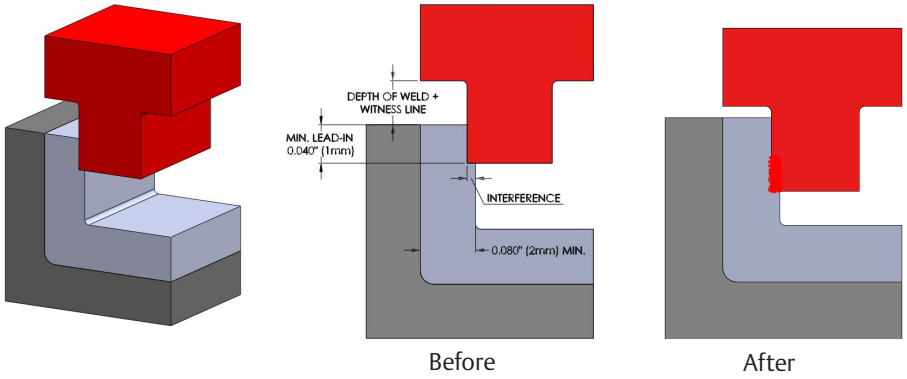


Figure 12. Joint Design with O-Ring for Hermetic Seal



Before After

Figure 13. Shear Joint Design

than 0.010 inch/0.254 mm tall), thus resulting in lower weld strengths. The knife edge can be 0.015 inch to 0.020 inch (0.381 to 0.508 mm) tall and should utilize a 45° angle. Another benefit of the chisel energy director is that it can be placed at the inside edge of a step and assure that it will not slip off the narrow welding ledge. Also, it can be used to direct the flow of molten material away from an opening (i.e around the perimeter of a lens).

Note: As weld strength will be limited to weld width, a textured surface should always be added when using this design.

Specialized Joints — In order to achieve a hermetic seal in less easily welded resins or irregular shapes, it may be necessary to use a compressible seal or a convoluted path for melt flow. Figure 12 shows a joint design incorporating an O-ring. It is important to note that the O-ring should be compressed a maximum of 10 to 15%, only at the end of the weld. Pins and sockets (stud welding, not staking) can also be used successfully with an O-ring design. (See datasheet PW-5.)

Shear Joint — An energy director type of joint design in some cases may not produce the desired results with semi-crystalline resins such as nylon, acetal, polypropylene, polyethylene, and thermoplastic polyester. This is due to the fact that semicrystalline resins change rapidly from a solid to a molten state, and back again, over a relatively narrow temperature range. The molten material flowing from an energy director, therefore, could re-solidify before fusing with the adjoining interface. The weld strength in a semi-crystalline resin could be limited to the base width of the energy director. A **shear joint** configuration is recommended for these resins where geometry permits.

With a shear joint design, welding is accomplished by first melting the small, initial contact area and then continuing to melt with a controlled interference along the vertical walls as the parts telescope together (Refer to Figure 13). This allows a strong structural or hermetic seal to be obtained as the molten area of the interface is never allowed to come in contact with the surrounding air. For this reason, the shear joint is especially useful for semi-crystalline resins.

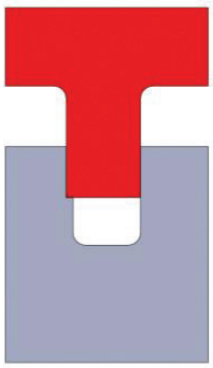


Figure 14. Tongue and Groove Variation

Figure 15. Shear-Joint Variation

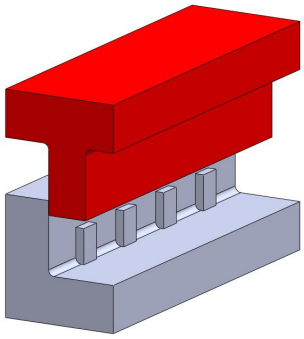


Figure 16. Interrupted Shear Joint Design

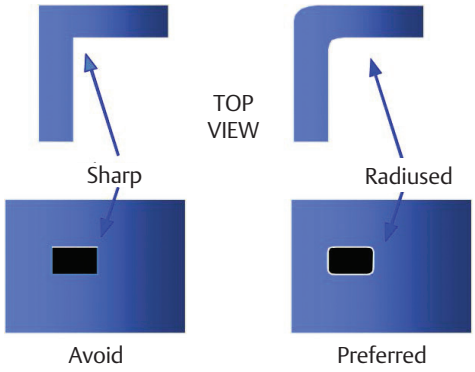


Figure 17. Radius of Corners to Reduce Stress

The strength of the welded joint is a function of the vertical dimension of meltdown of the joint (depth of weld), which can be adjusted to meet the requirements of the application. The general guideline for depth of weld is to use 0.75X the wall thickness.

In order for a shear joint to be successful, the following conditions must be met:

- The shear joint requires rigid side wall support to prevent deflection during welding. The walls of the bottom section must be supported at the joint by the holding fixture, which conforms closely to the outside configuration of the part.
- The top part should be of sufficient structural integrity to withstand internal deflection. Similarly, the minimum wall thickness of the bottom part should be 0.080 inch (2.00 mm) to prevent buckling.
- The surfaces creating the interference between the top and bottom parts should be flat and at 90° from each other.

A shear joint is not recommended:

- For parts with a maximum dimension of 3.0 inch.
- Parts with sharp corners, or irregular shapes. This is due to difficulty in holding the molding tolerances necessary to obtain consistent results.

An energy director type joint would be suggested for parts falling outside of these conditions.

For a midwall joint, the tongue and groove variation shown in Figure 14 is preferred. It is also useful for large parts. Interference on one side only is recommended.

When welding parts that need a structural weld only (hermetic or air-tight seals are not required), use the shear joint design with interrupted vertical energy directors shown in Figure 16. This design reduces the overall area and subsequent energy or power required to weld the parts. The potential for part marking is also minimized.

SHEAR JOINT GUIDELINES

The following table gives general guidelines for interference and part tolerance in relation to maximum part dimension.

Maximum Part Dimension	Interference per Side (Range)	Part Dimension Tolerance
Less than 0.75” (18 mm)	0.008” to 0.010” (0.2 to 0.254mm)	+-0.001” (+-0.025 mm)
0.75” to 1.50” (18 to 35 mm)	0.010” to 0.014” (0.254 to 0.356mm)	+-0.002” (+-0.050 mm)
1.50” to 3.0” (38 to 76mm)	0.014” to 0.018” (0.356 to 0.457mm)	+-0.003” (+-0.075 mm)

Other Design Considerations for Any Joint Design

Sharp corners localize stress. When a molded part with stress concentration is subjected to ultrasonic mechanical vibrations, damage (fracturing, melting) may occur in the high stress areas. This can be mitigated by having a generous radius (0.020 inch/0.508 mm) on corners, edges, and junctions. At a minimum, all corners or edges should be broken (Refer to Figure 17).

Hole or Voids, like ports or other openings in the part being contact by the horn can create an interruption in the transmission of the ultrasonic energy (Figure 18). Depending on the type of material (especially semi-crystalline resins) and the size of the hole, little or no welding may occur directly beneath the opening. When a hole or bend exists in the part, the resin dampens the transmission of energy, making it difficult to pass vibrations from the horn contact point to the interface of the parts to be welded, especially in shear.

Careful attention must be given to the design of parts to avoid such problem areas. Air bubbles within the plastic, due to improper venting in the mold tool, will also dampen the transmission of vibrations or cause the material to blow out in these areas.

Near-field vs. far-field welding — Near-field and far field welding refer to a joint less than 0.250 inch, or more than 0.250 inch from the horn contact surface, respectively (Figure 19).

In amorphous plastics, the random arrangement of molecules allows the vibrations to pass through easily with little attenuation. Comparatively, because of their structure, semi-crystalline resins dampen the transmission of energy, making them more difficult to weld in a far-field condition. Dampening also takes place in low-stiffness resins (low modulus). Care must be taken when designing parts to allow adequate transmission of energy to the joint area.

Appendages, tabs, or other details molded on to the interior or exterior surfaces of the molding can be affected by the mechanical vibrations, resulting in fracturing (See Figure 20).

The following are recommended to minimize or eliminate this:

- The addition of a generous radius to the area where the appendages intersect the main part.

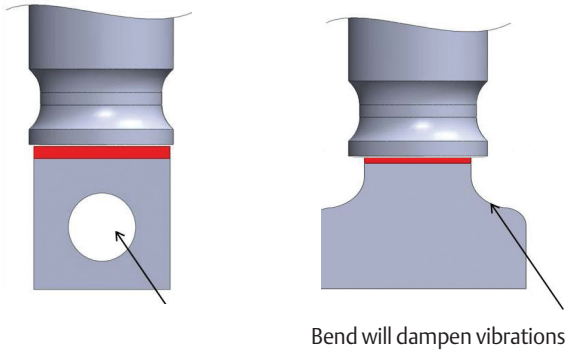


Figure 18. Interference with Energy Transmission

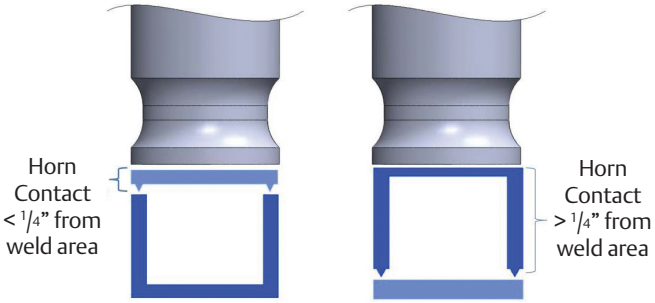


Figure 19. Near-Field and Far-Field Welding

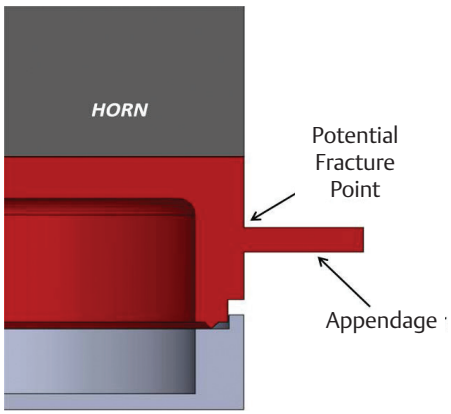


Figure 20. Part Surface Detail Design

Ultrasonic Plastic Joining

- Dampening of flexure through external means.
- Increasing the stiffness of the appendage by either increasing its thickness or adding ribs or gussets to that feature.
- Evaluation of other frequencies.

Diaphragmming — an "oil-canning" effect with related burn-through —typically occurs in flat, circular parts at thin-walled sections of the part (e.g., a living hinge) contacted by the horn (See Figure 21). This can be corrected by one or a combination of the following:

- Shorter weld time.
- Higher or lower amplitude.
- Amplitude Profiling.™
- Nodal plunger on horn.
- Thicker wall section.
- Internal support ribs.
- Evaluation of other frequencies.
- Positive air pressure from the horn nodal area to the face.
- Pulling vacuum via the fixture.
- Welding with a vented horn.

Horn contact and placement can play a major role in the successful welding of molded parts. In general, the horn should be large enough to overhang the perimeter of the parts, so it is bearing directly over the joint area (Refer to Figure 22). Doing this helps direct the mechanical energy and prevent marking of the contact surface. The surface of the horn or part can also be raised over the weld area to provide better contact, which can improve the consistency of energy transmission.

Note: The area of horn-to-part contact must be larger than the total weld area. Failure to do this could lead to surface marking.

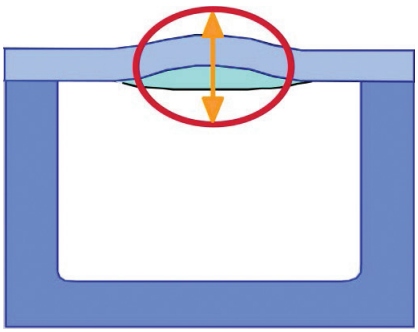


Figure 21. Diaphragmming

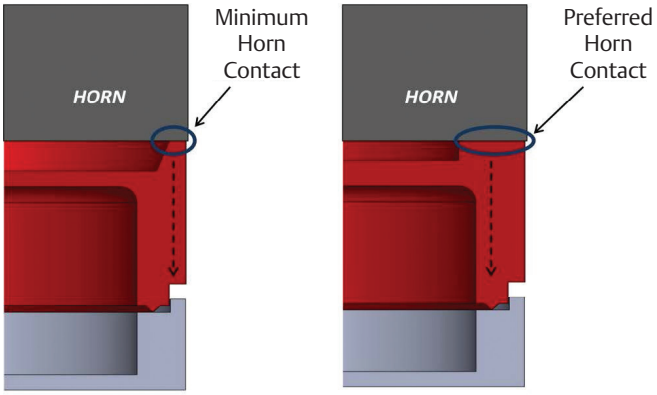


Figure 22. Proper Horn Contact and Placement

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