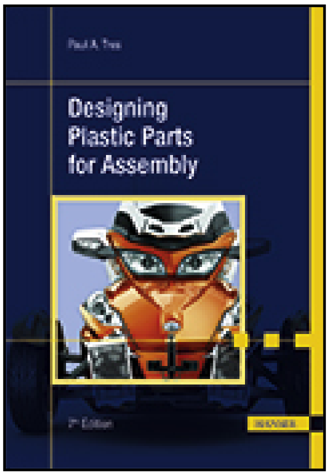

Sample Pages

Paul A. Tres

Designing Plastic Parts for Assembly

ISBN (Buch): 978-1-56990-555-5

For further information and order see

http://www.hanser-fachbuch.de/978-1-56990-555-5

or contact your bookseller.

Contents

5 Welding Techniques for Plastics 83

7 Living Hinges 217

Preface to the Seventh Edition

I am pleased and honored that Paul Tres has invited me to write the preface for the seventh edition of Designing Plastic Parts for Assembly. Paul is an outstanding expert in the plastics field, and Designing Plastic Parts for Assembly enjoys a well-deserved reputation as an indispensable resource. His book is an excellent and accessible reference work on all issues pertaining to the design and manufacture of plastic parts.

One of the strengths of Paul's book is his integration of lucid descriptions of fundamental material and manufacturing principles with case histories and real-world examples, and this new edition continues and expands upon this approach. Paul explains the reasons behind each principle and, in many instances, illustrates it with an example that helps make the information accessible to experts and laypeople alike. The need to avoid sharp corners in design, for instance, is illustrated by the tragic case of the DeHavilland Comet, which suffered catastrophic failures when the corners of its passenger windows (which were square) failed under the constant stress of pressurization and depressurization. The need to conduct stress/strain curves specific to the polymer resin mix being used for a particular application, in turn, is illustrated by the failure of a snap-fit latch designed to hold a defibrillator battery in place. Because the snap-fit latch did not hold the battery in place, the defibrillator failed to perform when it was needed to save a life. In the testing that occurred in the ensuing litigation, it was determined that the vendor's stress/strain curves had been done using only unpigmented product, and were not accurate for the product to which coloring agents had been added.

Illustrations such as these highlight the fact that selecting the proper materials and design approach are critical not just to the bottom line, but to ensuring consumer safety. Although the world of plastic manufacturing is constantly evolving, core principles still remain as important as ever. As a source of information on these issues, Paul's book is of great value not just to engineers and designers, but to other professionals as well. As an attorney who represents consumers in product liability litigation, I met Paul when I needed an expert to help me investigate the catastrophic failure of a plastic wheel rim. Through the application of basic principles set forth in his book, Paul has identified several ways in which the product in question failed to measure up to basic manufacturing standards. Indeed, if the manufacturer had heeded and applied the basic principles described in Paul's book, the rim would not have failed and my client would not have been injured.

Whether you are in the manufacturing field or, like me, in a profession in which it is important for you to understand the principles of plastic parts design and manufacturing, Paul's book, and his expertise, are unparalleled resources.

Cleveland, Ohio *David M. Paris, Esq.*
Nurenberg, Paris, Heller & McCarthy Co., L.P.A.

Foreword to First Edition

Knowing well the work and many special talents of Paul A. Tres, I take delight in the opportunity to introduce his new book, Designing Plastic Parts for Assembly, and recommend it to a broad range of readers. Material engineers, design and manufacturing engineers, graduate and under-graduate students, and all others with an interest in design for assembly or plastic components development now have a clearly written, method-oriented resource.

This practical book is an outgrowth of the like-named University of Wisconsin–Madison course which is being offered nationally and internationally. Just as his lectures in the course provide a detailed yet simplified discussion of material selection, manufacturing techniques, and assembly procedures, this book will make his unique expertise and effective teaching method available to a much larger audience.

Mr. Tres' highly successful instructional approach is evident throughout the book. Combining fundamental facts with practical techniques and a down-to-earth philosophy, he discusses in detail joint design and joint purpose, the geometry and nature of the component parts, the type of loads involved, and other vital information crucial to success in this dynamic field. Treatment of this material is at all times practice-oriented and focuses on everyday problems and situations.

In addition to plastics, Mr. Tres has expert knowledge in computer software, having directed the development of DuPont's design software. The course at the University of Wisconsin–Madison is indirectly an outgrowth of the software he designed for living hinges and snap fits at DuPont.

Mr. Tres holds numerous patents in the plastics field. He is known worldwide for his expertise in computer programming, manufacturing processes, material selection and project management on both a national and international scale.

Most recently, Mr. Tres' accomplishments have earned him the DuPont Automotive Marketing Excellence Award as well as recognition in the 1994–1995 edition of Who's Who Worldwide.

Whether you are just entering the field, or are a seasoned plastic parts designer, Designing Plastic Parts for Assembly is an excellent tool that will facilitate cost-effective design decisions, and help to ensure that the plastic parts and products you design stand up under use.

Madison, WI *Dr. Donald E. Baxa*

University of Wisconsin-Madison

Preface to First Edition

It gives me great pleasure to write this preface for such an important contribution to engineering design. It is rather sad fact that while the creative use of plastics has changed the very structure of consumer products over the past decade, many engineering students graduate with very little knowledge of polymer engineering or plastic design principles. This book written by a recognized expert and practitioner in the field of plastic component design is both a valuable text for engineering courses and a resource for practicing design engineers.

The full potential for the use of plastics in consumer products became recognized in the mid 1980s through the pioneering development of the IBM ProPrinter. The ProPrinter destroyed the myth, prevalent amongst product engineers at that time, that such design elements as plastic springs, plastic bearings, plastic securing elements, etc., lacked the structural integrity of their more common metal counterparts. In the ProPrinter, not only were these plastic design features shown to have the required reliability in regular use and abuse, they were combined into single parts to produce a new level of design elegance. For example, the injection molded side-frames of the ProPrinter, which support the rollers and lead screw, incorporated bearings for all of these rotating members, springs to maintain the required paper pressure, and cantilever securing elements to allow the frames to be snap fitted into the base. The result of such innovative design details produced a desktop printer which could be assembled in only 32 final assembly steps compared to the 185 steps required to assemble its main competitor in the marketplace.

Since the emergence of the ProPrinter, smart plastic design has become an essential tool in the competitive battle to produce products which have simpler structures with smaller numbers of discrete parts. Part count reduction, in particular, has been shown, through numerous case studies published over the past five years, to have a ripple effect on product manufacture which improves the efficiency of the entire organization. Fewer parts mean fewer manufacturing and assembly steps, and fewer joints and interfaces, all of which have a positive effect on quality and reliability. Moreover, a reduction in the number of the parts results in a direct attack on the hidden or overhead cost of an organization. Thus, fewer parts also mean fewer vendors for purchasing to deal with, less documentation, smaller inventory levels, less inspection, simpler production scheduling and so on.

Designing Plastic Parts for Assembly tackles all of the important issues to be faced in designing multi-feature complex plastic parts. The book is thus much more than its title suggests. It deals with essential fundamentals for the development of competitive consumer products.

Providence, Rhode Island *Dr. Peter Dewhurst*

Department of Industrial and Manufacturing Engineering
University of Rhode Island

5 Welding Techniques for Plastics

There are many different methods for welding two parts together. All variables, such as materials, design, and conditions under which the finished product will be used, including cost of the process, must be considered when deciding which welding technique should be employed.

Polymers can be melted, and therefore welded, using relatively little energy. Heat, friction—even ultrasonic vibrations and radio frequencies—can be used to create the melting necessary for a polymer weld. Welding methods include ultrasonic welding, ultrasonic heat staking, hot plate welding, spin welding, vibration welding, and laser welding. Welding requires no additional materials with one exception: electromagnetic welding, which requires bonding agent consumables.

5.1 Ultrasonic Welding

The principle behind ultrasonic welding technology is based on vibration. One of the parts being assembled is vibrated against the other, stationary one. Heat generated through vibration melts the materials at the joint interface to accomplish the weld.

Thermoplastics are the only polymers suited for this process. Thermoset materials do not melt when reheated because of their intermolecular cross-links.

5.1.1 Ultrasonic Equipment

The type of equipment required for an ultrasonic welding process depends upon the size of the manufacturing operation. The ultrasonic welding equipment requirements of a large-volume production environment will be different from those of a small prototype operation. They will, however, be very similar in principle.

A typical ultrasonic welding system consists of a power supply, also referred to as an *ultrasonic generator*; a *converter*, also known as a *transducer*; a *booster*; and a *horn* (see Fig. 5.1). The horn is a metal bar designed to resonate at a certain frequency, delivering the actual energy to the parts to be welded. The converter, booster, and horn are mounted inside a frame, which can slide along the stand, allowing them to travel vertically under the power of a pneumatic cylinder. The pressure applied by the air cylinder can be preset for manual systems or fully controlled by a computer for automatic systems. The pressure, trigger pressure, stroke speed, and stroke travel are all adjustable through the control panel or by the computer. The two palm buttons are used by the operator to activate the machine.

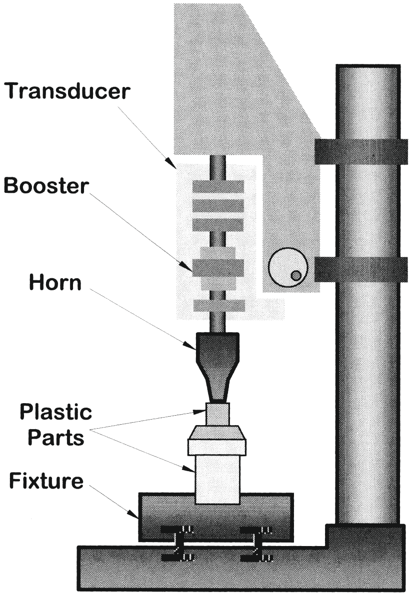

Figure 5.1
Ultrasonic welder

To generate the necessary amount of vibration required for a particular assembly, an electrical current is passed through a stack of crystalline ceramic material that possesses *piezoelectric* properties, which allow the material to change its size. The electric power supply has a frequency of 50 to 60 Hz. Once an electric current is applied, the material expands and contracts at a very high frequency, converting the electrical energy into mechanical energy or vibrations. These vibrations occur with frequencies ranging from 15 to 70 kHz. The most common output in ultrasonic welding systems provides frequencies of 20 to 40 kHz.

The distance the mechanical vibrations travel back and forth is called the *amplitude*. A typical converter of 20 kHz could have amplitudes of 0.013 to 0.02 mm (0.0006 to 0.0008 in.) between its maximum expansions and contractions.

Figure 5.2 Ultrasonic welder HiQ Dialog also includes software to control and operate the welding process and machine functions, having the additional capability of welding visualization in two graphic modes: EasySelect and Expert mode *(Courtesy of Herrmann Ultrasonics)*

There are different types of ultrasonic welding systems for different applications. An integrated welder (see Fig. 5.1) is a self-contained unit, which has a power supply, actuator, and the acoustic components packaged as a stand-alone system. Advantages of this type of system include low investment cost and ease of service.

Modular systems include, in addition to the welder, a rotary indexing table and an in-line conveyor. These systems are ideal for assembling large numbers of parts. Also, their components are interchangeable and easy to upgrade.

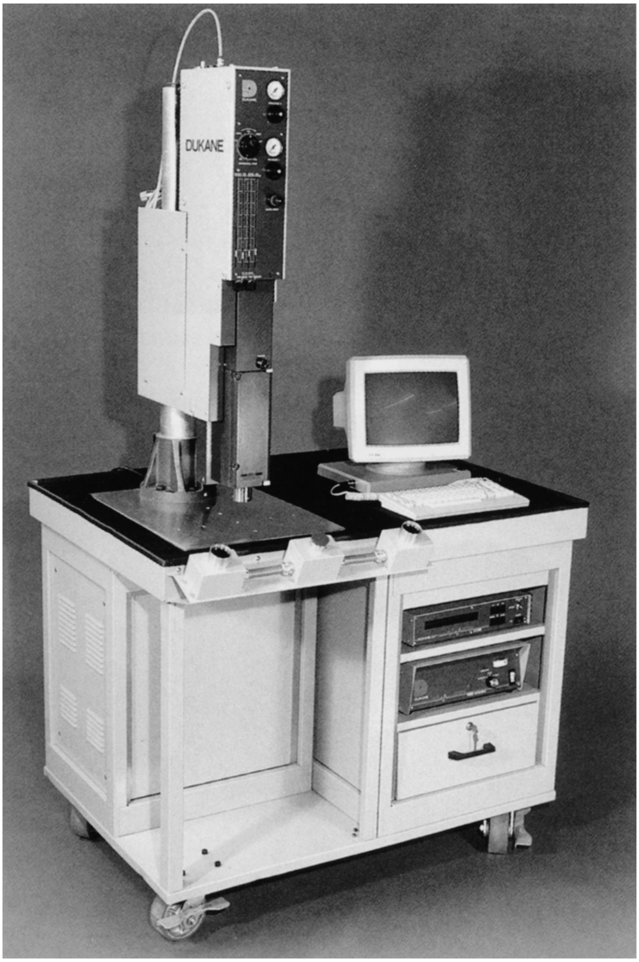

Figure 5.3 Mobile ultrasonic workstation. An aluminum top plate acts as the base plate for the press table. The generator and controller are on the recessed shelves *(Courtesy of Dukane Corporation)*

Modular systems are available in semiautomatic and automatic models. Automatic systems include a pick-and-place robot arm.

Power level is frequently determined by the cycle time or the material used in a given application. Power supplies are available from 150 to 3200 W for the 20 kHz machines, and from 150 to 700 W for 40 kHz systems.

Controls are integrated into the power supply and may be analog or digital. Digital controls are computer controlled.

The frame or box contains the converter. The vibration produced by the converter must be amplified further in order to produce meaningful results when it reaches the horn face.

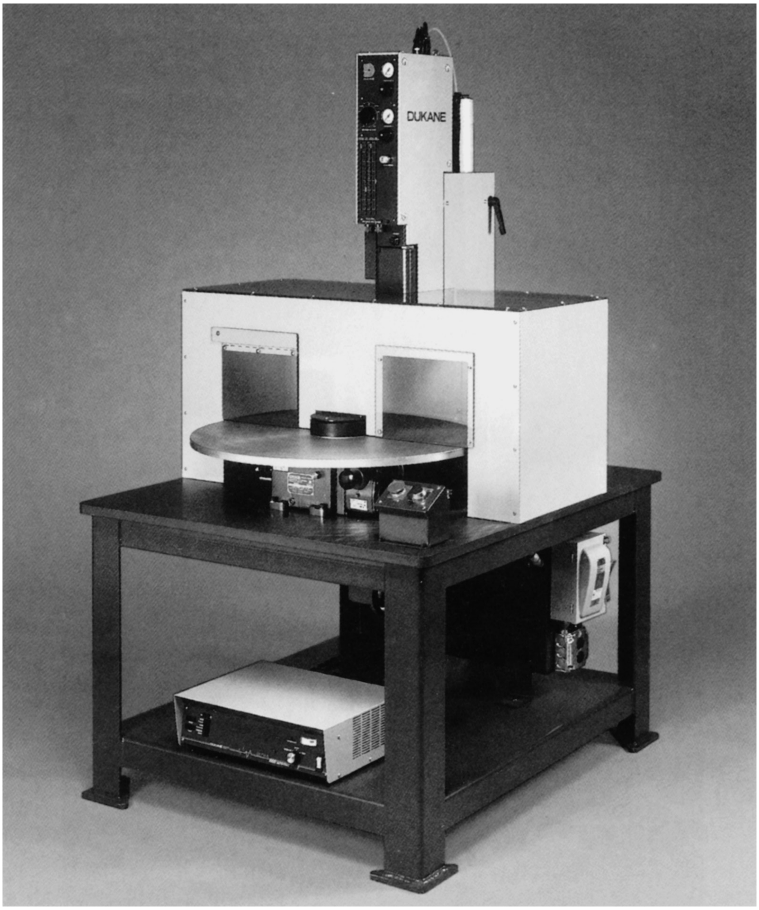

Figure 5.4 Semiautomatic ultrasonic press with rotary index table *(Courtesy of Dukane Corporation)*

5.1.2 Horn Design

When the horn receives high energy in the form of vibrations from the booster, it reaches its resonant frequency. At that time, the ends will expand and contract longitudinally about its center (also called the *nodal point* of the horn), alternately lengthening and shortening the horn's dimensions. The movement from the longest length value to the shortest length value at the horn face (the portion of the horn in contact with the part) is referred to as the *horn amplitude*. The face of the horn is usually machined to conform to the plastic part with which it comes in contact.

The horns are designed as resonant elements with a *half wavelength*. The materials for horns must have low acoustical impedance (low losses at ultrasonic frequencies) and high fatigue strength.

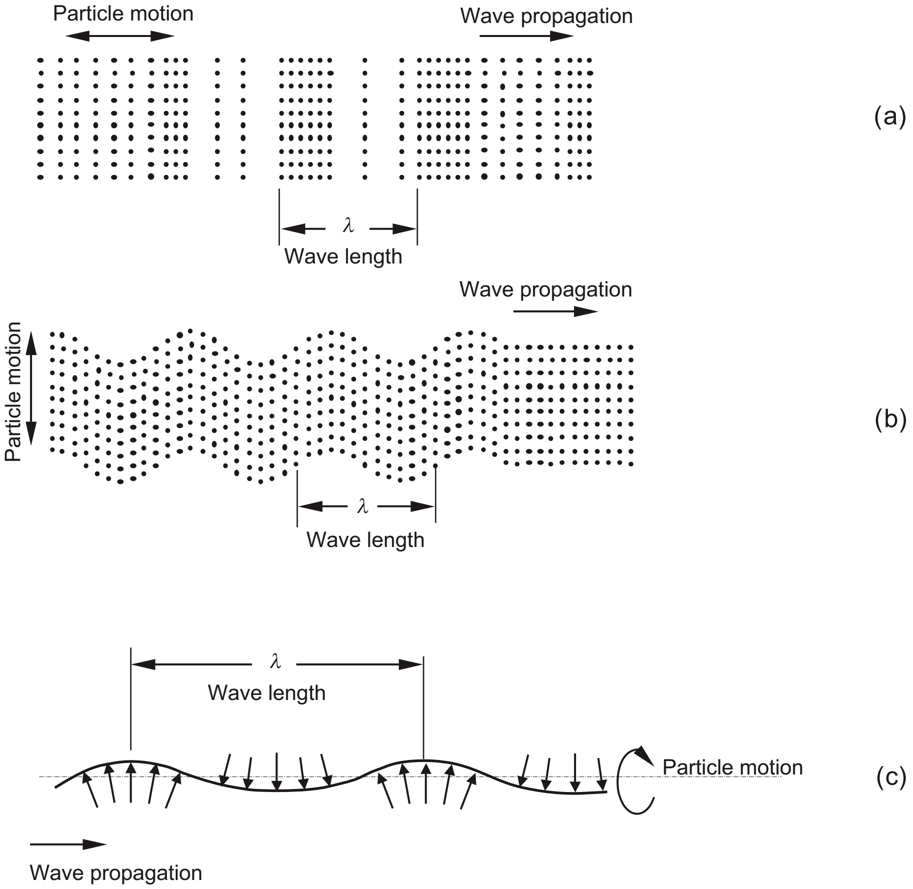

Figure 5.5 Ultrasonic waves: (a) longitudinal; (b) transverse; (c) curved

There are three types of vibrations produced in the ultrasonic welding process. The first type is the *longitudinal wave*. These waves are transmitted in a direction parallel to the horn axis, which is vertical to the stand. The oscillations are a function of the wavelength *λ (lambda)*, both in amplitude and direction. Longitudinal waves (see Fig. 5.5(a)) act as energy carriers to allow a proper weld, and they are the only desirable type of vibrations in an ultrasonic welding process.

A second type of vibration is the *transverse wave*. Typically, transverse waves are electromagnetic waves of very high frequency and can be generated only in the presence of shear stresses. Transverse waves move in a direction normal to the horn vertical axis (see Fig. 5.5(b)). Transverse waves should be avoided because they create vibrations only at the horn surface and not in the entire horn body. As a result, almost no energy is transmitted to the parts to be welded.

The third type of vibration consists of *curved waves*. These waves are detrimental to the ultrasonic welding process and will occur when the system components are out of balance due to misalignment, for example. This results in uneven pressure reaching the part, creating a nonuniform weld. During the transmission of ultrasonic waves from the transducer to the horn, curved waves returning from the horn to the piezoelectric material could crack the ceramic material. Curved waves generate high compression and tensile loads in the parts being welded (see Fig. 5.5(c)). In order to correct the system imbalance, asymmetrical masses can be placed on the misaligned components to bring the system back into balance. Horns should be designed to completely avoid transverse and curved waves.

Horns are commonly made from aluminum, titanium, Monel metal, stainless steel, and steel alloys. These materials have different properties, which are beneficial for different applications. An important consideration when selecting a horn material is that the material should not dissipate acoustical energy.

Titanium is one of the high-strength materials with the best acoustical properties, and it wears better than other horn materials.

Aluminum, although it does not wear as well as titanium, is the best of the low-strength materials. Aluminum has low amplitude and is appropriate for assembling large parts.

Steel materials are best for low-frequency losses or *premiation*. Steel has high wear but loses a great deal of its own frequency. It is good for low amplitudes and high wear such as ultrasonic metal inserting.

Carbide-faced titanium is recommended for high-amplitude horns and high-wear applications.

5.1.3 Ultrasonic Welding Techniques

In order to achieve a proper ultrasonic weld, the horn must be applied as close to the joint as possible. To help ensure an accurate weld, a *nest* or supporting fixture is required to hold the parts together. Fixtures have two purposes: to provide alignment between the parts and the horn, and to provide support to the weld area. The nest is made of chrome-aluminum or epoxy and steel.

Figure 5.6 shows a fixture that provides nesting for the parts as well as accurate location and securing of the part. The fixture holds the part in place by applying a vacuum for the duration of the weld cycle. Once the cycle is completed, the vacuum is reversed to create an air pressure, which ejects the final assembly from the nest.

The majority of fixtures are machined or cast. These manufacturing processes create fixtures that engage the lower part and hold it securely in a given position. Variations in thickness and flatness of the parts close to the joint area can adversely affect the welding process. To accommodate such variations, fixtures may be lined with rubber or rubbery material, such as silicone. Rubber or silicone strips allow the part to align in the fixture under nominal static loads and act as rigid constraints during the high-frequency vibration phase of the process. They also may help absorb random vibrations, which can often create cracking or melting in regions away from the joint area.

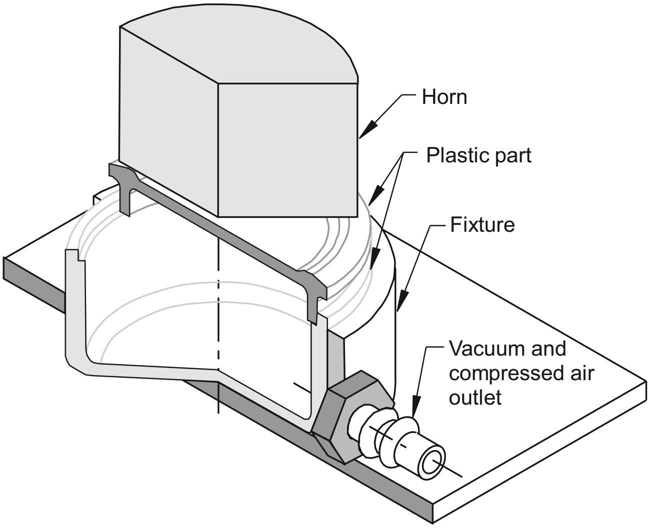

Figure 5.6
Air-assisted fixture design

There are various factors that influence the ultrasonic welding process. Polymer (material to be welded), part geometry, and wall stock (thickness) all affect the transmission of the mechanical energy to the joint interface. These factors also influence the design of the fixture.

The booster or amplifier regulates the vibration, keeping it at the appropriate level to melt the correct amount of resin in the weld area for the most efficient weld possible. Boosters are made of titanium or aluminum and are color-coded to identify the amount of amplitude they can generate.

The overall ultrasonic weld cycle (see Fig. 5.7) can vary from a fraction of a second up to a few seconds, depending on the part size and joint area. The hold time could be anywhere from 0.25 second to approximately 1 second, again depending on the size and shape of parts to be assembled.

The horn transfers the vibrational energy it receives from the booster to the parts to be assembled. The amount of amplitude the horn receives from the booster depends on the horn design. Different horn designs deliver different amplitudes.

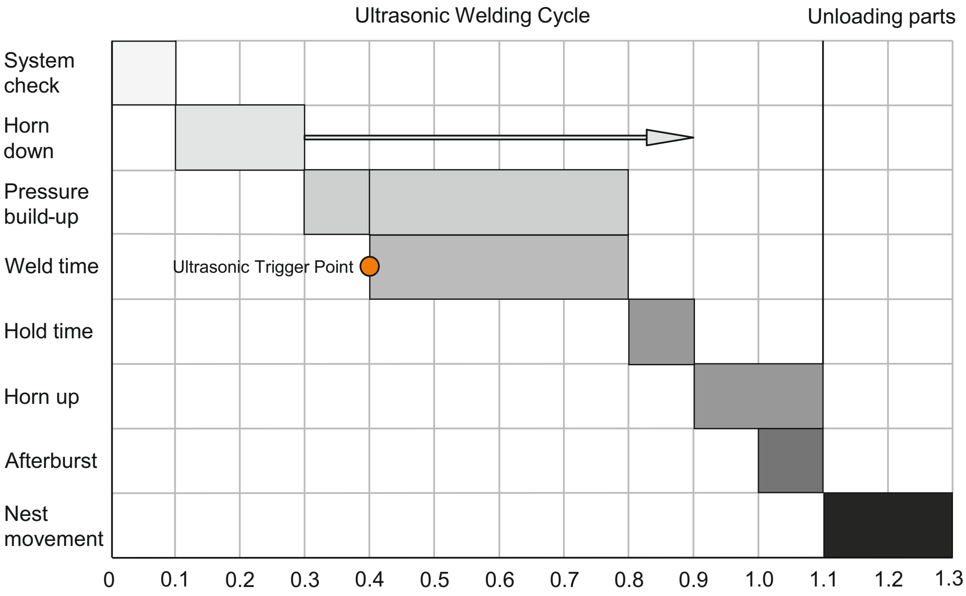

Figure 5.7 The welding cycle

Figure 5.8 shows a stepped horn arrangement, which is a convenient way of modifying the amplitude. By interconnecting horns, one can increase or decrease the amount of amplitude to which the last horn in a series can vibrate. The horn in the middle of the arrangement in Fig. 5.8 is also called the booster horn.

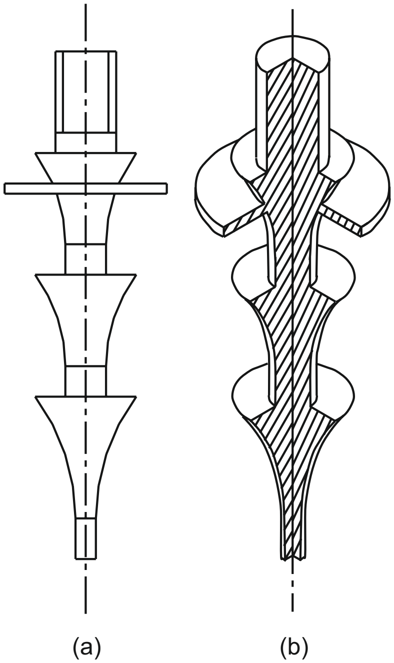

Figure 5.8
Stepped horn arrangement

It is important to avoid overstressing horns when interconnecting them. This could lead to failure of the system through fatigue.

The ratio between the amplitude generated by the converter (also called input amplitude) and the amplitude at the end of the horn in contact with the part welded (output amplitude) is called *gain*. The gain itself is a function of the transversal area between the converter (input section) and the horn face (output section).

If the cross-sectional area of the output end is less than that of the input end, the gain will be greater than 1 and the corresponding amplitude will increase.

There are different horn shapes for various welding applications. Stepped, conical, exponential, catenoidal, or Fourier horns can be connected at the stress antinodes, the point between two adjacent peaks in the wave pattern. Larger horns (greater than 75 mm or 3 in.) can be constructed with slots cut out to change the resonating frequency by more than a quarter of a wavelength. Each is designed to change the gain to a specific value.

5.1.4 Control Methods

Amplitude is the most important variable in determining the power output for the part to be welded. It is also very important in the horn design. The horn, as mentioned earlier, is a metal bar a half-wavelength long, dimensioned to resonate at a certain applied frequency.

Constant energy is the total amount of ultrasonic energy required by the mating parts and actually delivered to them (Fig. 5.9). There is a time window within the welding process when the total energy is applied to the joint area. The energy is delivered independent of any external influences such as voltage fluctuations. All other parameters, such as time or amount of travel—the downward vertical distance the horn moves during the process—are varied in order to determine their optimum values for a given joint design.

The relatively new computer-controlled ultrasonic systems greatly enhance the process by allowing direct control of the energy transmitted to the parts rather than controlling only the time.

Another technique of control is based on travel. Controlling travel is one way of controlling the weld quality. There are two ways of applying the control method: through partial travel and total travel.

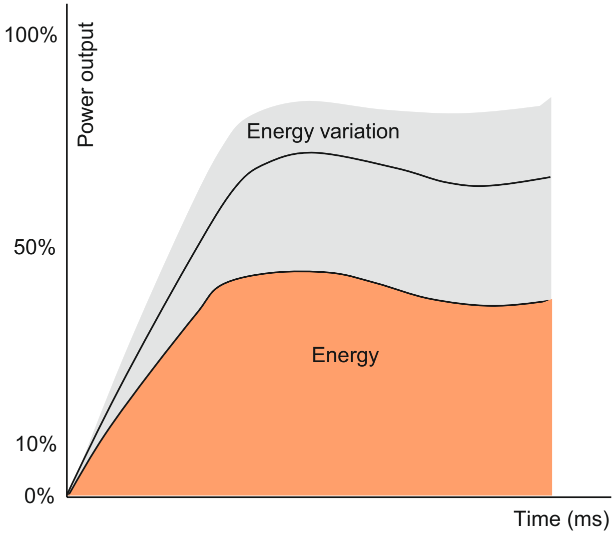

Figure 5.9 Constant-energy method of control

Partial travel implies that the horn is moving downward until it makes contact with the part to be welded. Once the horn makes contact, the circuit is closed by the digital readout sensor, and the ultrasonic is activated (see Fig. 5.10(a), ultrasonic activation point (UAP)). The pneumatic cylinder applies pressure until the top part reaches the ultrasonic deactivation point (UDP). The weld is completed.

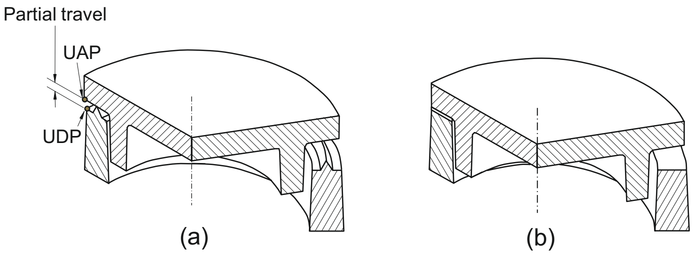

Figure 5.10 Partial-travel method of control (UAP represents the ultrasonic activation point and UDP represents the ultrasonic deactivation point): (a) before, and (b) after assembly

Sometimes the partial-travel method is not feasible, for example, when the parts are unstable. In these cases *total travel* or *absolute travel* is used. This is the best method when dimensional accuracy is the most important feature of the assembly. When total travel is used, the horn is deactivated only when a preset amount of travel is achieved.

The total-travel method (Fig. 5.11) uses a digital readout sensor mounted on the press to activate the horn before it makes contact with the part. The location of the sensor can be taken from a fixed reference point or by measuring the collapse of the plastic in the joint during the welding process (see Fig. 5.11(a), UAP point). The horn will stay triggered until it reaches the UDP position. Holding time starts once the preset travel is reached. A signal from the encoder is sent to the computer, which stops the flow of vibration energy to the horn.

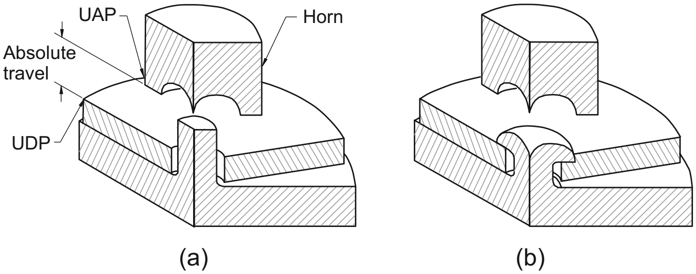

Figure 5.11 Absolute- or total-travel method of control (UAP represents ultrasonic activation point and UDP represents the ultrasonic deactivation point): (a) before, and (b) after assembly

While total travel is a preset distance, partial travel is usually limited to the height of the energy director.

Another method of controlling the weld is based on time. The *constant-time method of control* implies that the ultrasonic will be on for a predetermined time (usually 0.2 to 0.3 seconds) while the other parameter will be varied to determine optimum values.

For this method, time can be determined by an experienced operator through trial and error. Part size, materials, and other variables will influence the time selected.

The ultrasonic welding method produces joints with strength up to 90 or 95% of the virgin polymer. In some instances, hermetically sealed joints can be produced ultrasonically.

Another important factor in the welding process is the use of *far-field* and *near-field*.

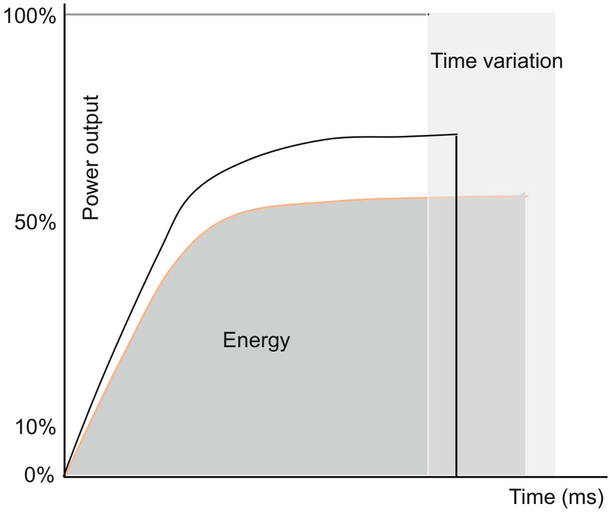

Figure 5.12
Constant-time method of control

The field refers to the distance between the joint weld area and the point at which the horn comes in contact with the part. When the distance is more than 7 to 8 mm (0.25 to 0.375 in.) it is referred to as a far-field weld. When the distance is less than 7 or 8 mm, it is a near-field weld. Special horns can be designed for assemblies requiring near- and far-field welds, but it is advisable to avoid combining near- and far-field welds in one assembly.

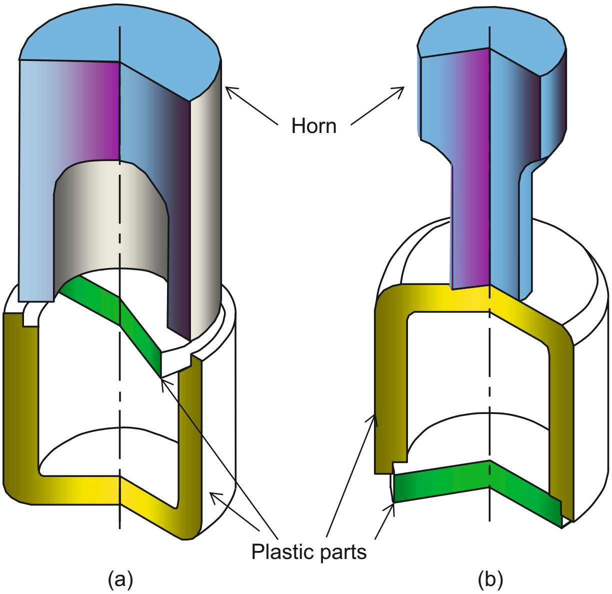

Figure 5.13
Horn position: (a) near-field, and (b) far-field

The frequency to be used in the weld depends on several factors, including the size of the part and the rigidity of the plastic. A general rule is that larger parts and softer plastics require lower frequencies. Sometimes, frequencies as low as 15 kHz may be used for very large parts in excess of 150 mm (over 6 in.). In these cases the horns are also quite large. Conversely, harder plastics and smaller parts require higher frequencies. Far and near fields also affect the choice of frequencies. Near-fields need higher frequencies; frequency decreases as the distance between the horn contact and the joint increases.

Also, the number and accuracy of controls determines the quality of the ultrasonic system. The timer controls the weld and hold time.

The melt temperature, Young's modulus, and overall structure usually determine the amount of vibration energy required for a specific weld. Rigid plastics exhibit the best weldability properties because they are good transmitters of vibration energy. Soft polymers, on the other hand, have a low value for Young's modulus or secant modulus. They dissipate the vibration energy, making the part difficult to weld. Softer polymers are, however, well suited for ultrasonic staking, forming, or spot welding.

Amorphous materials tend to soften gradually before melting and flow easily without solidifying prematurely.

Crystalline polymers do not readily transmit ultrasonic energy and therefore need higher energy levels than amorphous resins. Due to their sharp melting point they lend themselves more easily to controls, giving assemblies made from these materials a narrow margin of variation from part to part.

Mold-release agents such as zinc stearate, aluminum stearate, fluorocarbons, and silicones are not compatible with this process. If molding agents must be used in the molding process, a paintable grade should be selected. Incompatible agents can be removed with a Freon TF solution for crystalline polymers or a 50/50 solution of water and detergent.

5.1.4.1 Common Issues with Welding

As with any manufacturing process, problems may occur. The following is a list of common problems associated with ultrasonic welding, their probable causes, and possible solutions.

Overweld is usually caused by too much energy reaching the part. It can be corrected by reducing the pressure exerted by the pneumatic cylinder or by reducing the overall weld time. Other possible solutions include slowing the air cylinder motion and the use of a power control.

Nonuniform welds around the joint could have many possible causes. Warped parts could be one of them. The part dimensions, tolerances, and general processing conditions should be reviewed. A higher trigger pressure could be one of the solutions.

If the nonuniformity is created by the energy director's variance in height, the energy director should be redesigned. The problem could also be caused by a lack of parallelism between the horn, the nest, and the parts.

Sometimes flexure of the walls is the cause of nonuniformity. Ribs can be added to the part, or the fixture can be modified to prevent outboard flexure.

A knockout pin location in the joint area can result in an uneven weld. The knockout pin should be moved away from the joint area. Also, the knockout pin marks should be flush with the surface.

Insufficient support in the fixture can lead to nonuniformity. Improving support in critical areas, redesigning the nest, or switching from a flexible fixture to a rigid nest design may solve the problem. Sometimes the pressure from the pneumatic cylinder will cause larger sections of some parts to bend. This can be corrected by adding a rigid backup.

Tighter part tolerances or molding parameters are needed when the part tolerance is not within the part requirements.

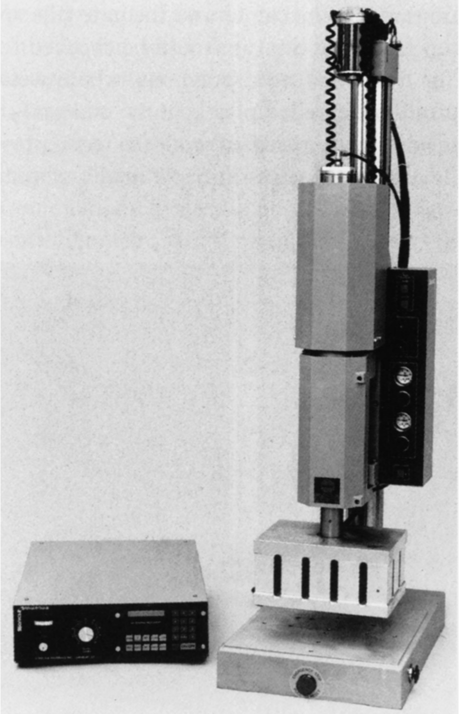

Figure 5.14
Ultrasonic welder has a power output of 4,000 watts and a frequency of 15 kHz. The horn dimensions are 300 mm by 350 mm (12 in. × 14 in.) *(Courtesy of Sonics and Materials, Inc.)*

Improper alignment is another possible cause of a nonuniform weld appearance. This can result from the part shifting during the weld cycle. Provisions for alignment in the mating parts need to be reviewed, and parallelism between the horn, part, and fixture should be rechecked.

A lack of intimate contact between the horn and the part can also cause a nonuniform weld. One has to make certain that there are no sink marks, raised symbols, or other inconsistencies to impede contact.

The presence of a mold-release agent on the part surface could also cause uneven welding. As mentioned earlier, parts should be cleaned prior to welding. If possible, a paintable mold-release grade should be used.

Fillers can also affect weld uniformity. If that is the case, processing conditions should again be reviewed, and the amount of filler should be reduced if possible. Also, the filler type—short fiber vs. long fiber—should be verified. It is also advisable to check for uniform filler distribution.

If the nonuniformity is a result of cavity-to-cavity variations (a cavity is an empty volume in a closed tool that becomes filled with polymer during the molding process), there will be a need to conduct a statistical study to determine if a pattern develops with certain cavity combinations. Both the cavity and the gate (the space provided in the tool for the molten polymer to reach the cavity) should be checked for excessive wear. This is particularly important for fiber-reinforced polymers, where wear is a major issue.

The percentage of regrind or degraded plastic in the material could be a problem. If so, the molding parameters should be verified and the percentage of regrind should be reduced. If the regrind is absolutely necessary, its quality should be consistent.

Drops in the pneumatic cylinder pressure should be combated by increasing the output pressure for the compressor. A surge tank with a safety valve may be added.

Changes in line voltage contribute to uniformity problems. This can be solved with a voltage regulator.

Marking is a welding deficiency that can have many different causes, a common one being an overheated horn. When this occurs, check for loose studs and a loose tip. Other possible solutions are simply to cool the horn, check that the coupling of the horn and the booster is correct, and ensure that no cracks are present in the horn. If the horn is made of titanium, the problem could be solved by switching to an aluminum horn. If the horn is made of steel, the amplitude should be reduced.

If marking is caused by localized high spots in the part, such as lettering or symbols, the horn will need to be redesigned in order to properly fit the part. Another solution may be to recess the lettering or symbols.

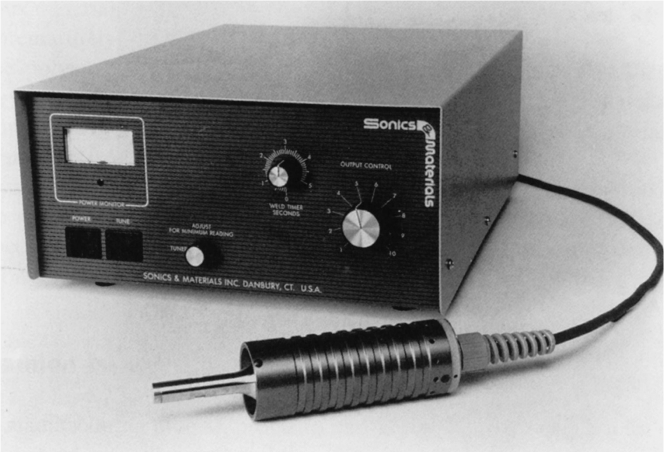

Figure 5.15 Ultrasonic handheld welder with replaceable horn (tip) *(Courtesy of Sonics and Materials, Inc.)*

Marks are often caused by the presence of aluminum oxide at the interface of the horn and the part. Aluminum oxide can be eliminated by using a chrome-plated horn and/or fixture or by applying a polyethylene film between the horn and the part.

Marking can also be created when a long weld cycle is used. Marking can be eliminated by reducing the overall weld cycle. This can be accomplished by lowering the amplitude or the pressure and adjusting the dynamic trigger pressure.

Flash in the weld can be the result of an energy director that is too large. Reducing the energy director size, reducing the weld time, and reducing pressure are all possible solutions. If the flash is caused by shear interference that is too great, the problem may be overcome by simply reducing the amount of interference. Flash can also be caused by poor part tolerances (too tight) and by nonuniform joint dimensions.

Misalignment of the welding assembly, which might suggest a poor initial design, could indicate the need for an alignment feature to be added to the parts. If improper support in the fixture is causing the misalignment, redesigning the fixture is recommended in order to provide proper support. Another option may be to shim the fixture. When misalignment is caused by wall flexure, with large sections deflecting, the addition of a rigid backup is suggested. Or the source of the misalignment problem may lie in improperly dimensioned joint design, in which case the parts must be redimensioned. Part tolerances and poor molding could also be the cause. Part tolerances should be tightened and molding conditions checked.

Internal components damaged during welding. This could be caused by excessive amplitude, which can be reduced by switching to a lower frequency. If long weld time is the cause, reduce weld time by adjusting the amplitude and/or pressure as well as the dynamic triggering pressure.

Internal damage can also be caused by too much energy entering the part. This can be corrected by reducing the pressure, weld time, or amplitude, or by using a power control. Also, proper mounting of the internal components should be verified. Sometimes a simple solution will be to isolate them from the housing or move them away from the area of high-energy concentration.

Melting or fracture of part sections outside the joint area. This problem is usually caused by sharp internal corners. In this case, a fillet should be used to radius or “round out” both the internal and the external corners. The correct internal radius should be equal to half the wall thickness. An external radius must be 1.5 times the wall stock.

If excessive amplitude is the cause, it can be reduced by changing to a lower booster. Fractures and melting can also come as a result of long weld time, in which case increased amplitude, increased pressure, or adjustments to the dynamic triggering pressure could correct the problem.

5.1.4.2 Joint Design

Joint design is a crucial component in successful ultrasonic welding. The design of the part and the materials used are important considerations in determining which joint design will be utilized.

5.1.4.3 Butt Joint Design

The butt joint design, also known as an energy director joint design or tongue-and-groove joint design, is appropriate for welding parts made mostly from amorphous resins, which lend themselves well to ultrasonic welding.

The joint should contain an energy director, which is a triangular protrusion or peak at or near the center of one of the faces. The peak provides line contact between the two surfaces to be welded. The volume (or area, as the calculations can be conducted in a 2-D plane if the part is symmetrical) of the triangular peak should equal the volume of the free space between the faces to be welded. This could be easily approximated with the areas of the two regions in a 2-D drawing. The melted material contained by the energy director or peak area should have an equal volume of space available to it in order to obtain a proper weld.

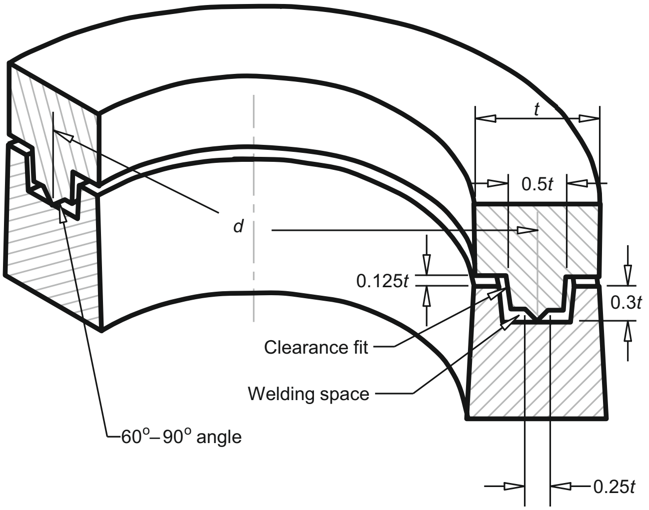

Figure 5.16 Butt joint, energy director, or tongue-and-groove joint design

The welding space or volume (the area in a 2-D cross-section drawing) should be at least three times the volume (or area) of an energy director for a butt joint design. This ratio increases as the angle decreases below 90°. Angles below 60° should not be considered.

The design shown in Fig. 5.16 provides a strong butt joint. This joint is difficult to mold, however, because of the clearance on both sides of the groove. The base of the energy director should be 0.25 times the wall stock. The angle should not exceed 90°. Usual values vary between 60° and 90°. The tongue width should be approximately half the wall thickness.

Equation 5.1 provides a formula to calculate the volume of polymer contained by the energy director for symmetrical welds (see Fig. 5.16).

$$V_{\text{Energy Director}} = 0.125t\left[\frac{\pi d^2}{4} - \frac{(d-0.25t)^2}{4}\right] \tag{5.1}$$

The following notation is used:

t = wall thickness (stock)

d = part diameter at the tip of the energy director

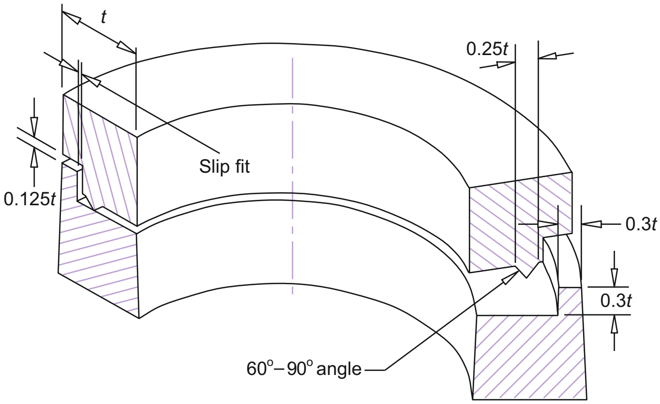

Figure 5.17
Butt joint: step design

To calculate the groove space needed:

$$V_{\text{Joint}} = 0.125t\left[\frac{(d+0.5t)^2}{4} - \frac{(d-0.5t)^2}{4}\right] \tag{5.2}$$

The butt joint step design is stronger than a pure tongue-and-groove design. The material flows into the slip fit clearance (Fig. 5.17), creating a seal that has good shear strength as well as tension strength. This design is based on an isosceles triangle. The height of the triangle should be a minimum of 0.5 mm (0.02 in.), and the base should be no less than 1 mm (0.04 in.).

Figure 5.18 shows other possibilities available in designing energy director joints or tongue-and-groove joints.

5.1.4.4 Shear Joint Design

Crystalline polymers require a joint design that provides a shearing action as the welding occurs. Figure 5.19 shows a typical shear joint. It should be noted that interference varies based on part dimensions. For small components with any dimensions in the X, Y, or Z direction less than 20 mm (0.75 in.), the interference should vary between 0.2 and 0.3 mm (0.008 to 0.012 in.). For medium-sized components with any dimensions between 20 and 40 mm (0.75 to 1.5 in.), the interference should increase to 0.3 up to 0.4 mm (0.012 up to 0.016 in.). Finally, for large part dimensions, which exceed 40 mm (1.5 in.), the interference should be between 0.4 and 0.5 mm (0.016 and 0.02 in.).

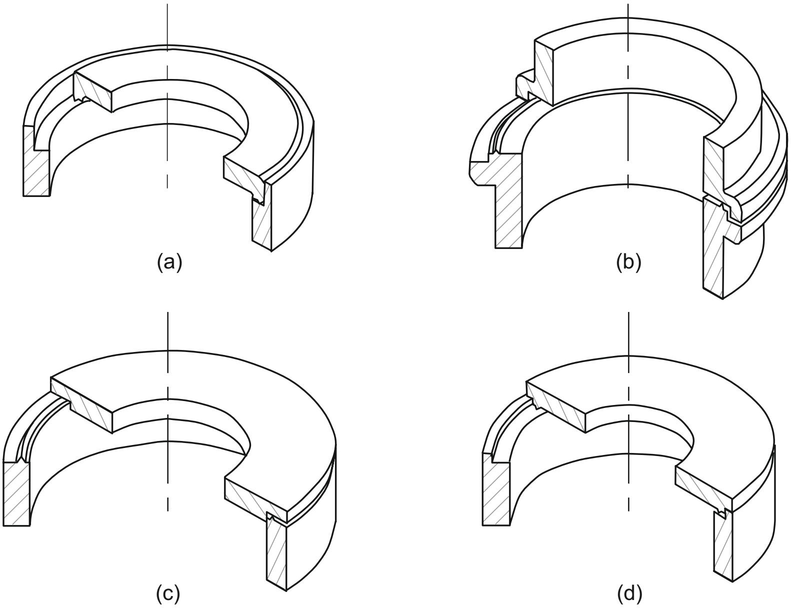

Figure 5.18 Variations of the butt joint design: (a) flat step; (b) double step; (c) flush step; (d) double flush step

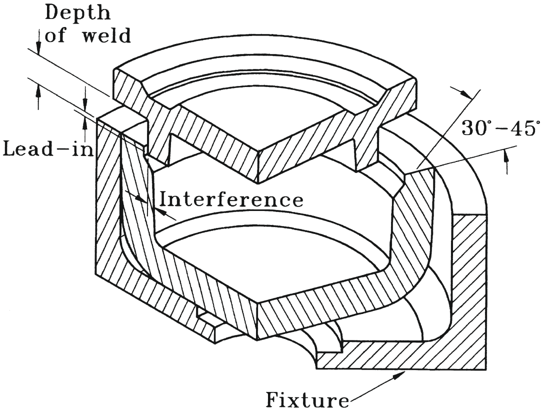

Figure 5.19
Shear joint design

The minimum lead-in recommended is between 0.5 and 0.6 mm (0.02 and 0.024 in.). The depth of the weld is related to the wall thickness and should be 1.25 to 1.5 times the wall stock.

The initial contact for this type of joint is limited to a small recess area in either of the parts. The recess helps the alignment of the parts during the welding process, which starts by melting the surfaces immediately on contact. Once the initial melting takes place, the parts continue to melt along the vertical walls, sliding together in a shearing process. The shearing action of the two melt surfaces eliminates possible leaks, resulting in good, leak-free seals.

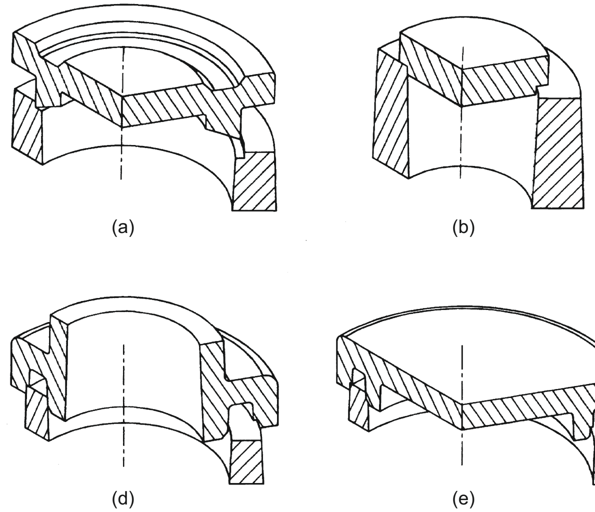

Figure 5.20 Variations of the shear joint design: (a) shear wedge; (b) flat shear; (c) guided shear; (d) control shear; (e) double shear; (f) double split shear

Figure 5.20 shows a few variations of the basic shear joint design. The joint designs shown in (d), (e), and (f) are mostly used for large parts (in excess of 80 mm). They help support the wall deflection that takes place during welding.

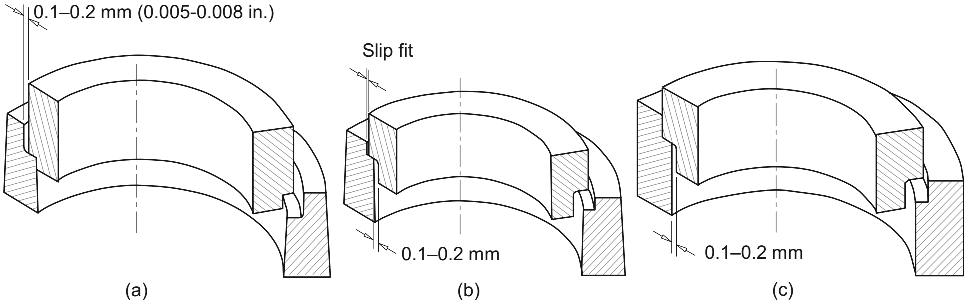

Figure 5.21 Shear joint designs with flash traps: (a) outside trap; (b) double trap; (c) inside trap

Index