



**Plastic Assembly Technologies, Inc.**  
8445 Castlewood Drive, Suite B, Indianapolis, IN 46250

## GUIDE TO ULTRASONIC WELDING

### Introduction

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Learn more about practical aspects of ultrasonic welding to enhance your assembly production. This Patsonics paper provides information on equipment, equipment setup, materials, joint designs and tooling to enhance your understanding of the ultrasonic welding process. This paper is primarily focused on ultrasonic welding. There are many other uses of ultrasonic equipment for assembly, including staking, insertion, swaging and film and fabric welding. It is not our intent to cover in detail these types of ultrasonic assembly methods. Our intent with the initial introduction of this paper is to focus on using ultrasonics for welding plastics. To understand and improve the ultrasonic welding process, one needs to have a basic knowledge on the principles outlined in this paper.



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## CHAPTER ONE

### The Critical Equipment Components

Knowledge of the components that make up the ultrasonic assembly system will help one understand the welding process and how they can implement setup solutions for a given application. To begin our understanding of the ultrasonic welding process, it is necessary to understand the basic components that make up an ultrasonic welding system. The system usually consists of six basic components.

1. The **ULTRASONIC POWER SUPPLY** changes 50/60 Hz electrical energy into high frequency electrical energy and the power supply is rated in watts of available output power. The frequency output of a power supply is fixed and frequencies are typically available in 15, 20, 30 and 40 KHz. The power output available ranges from 150 watts to 4000 watts of power depending upon the frequency. It is important to remember that just because a unit is rated at a certain output power capacity does not mean that an application will require full power from the supply or that the power supply will have adequate power for a given application. The power supply provides power on a demand basis depending upon the amount of power required for the application and under a given set of welder setup conditions. The size and shape of the part, the material being welded, the joint design, the power supply design and the setup variables can alter the amount of power drawn from a power supply. Applying increased pressure to the welder will result in an increased power draw. Increasing the output amplitude will increase the power draw. We recommend that once you know you have sufficient power for your application, you purchase as much power as your budget allows. This gives you a cushion without any loss in benefits.
2. The **CONVERTER** or **TRANSDUCER** is the motor of the ultrasonic system. This component produces a motion via a piezoelectric effect, which is to say that the converter expands and contracts when electrically excited by the power supply. At 20 KHz, this expansion and contraction is approximately .0008 of an inch at the face of the converter and the movement is in an axial motion. The converter is matched to the output frequency of the power supply. Also, the converter is matched to the impedance of a specific brand of power supply. It is important to purchase and use converters designed for the power supply.



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3. The **BOOSTER** is a machined piece of aluminum or titanium metal, which is tuned to resonate at the desired frequency and designed to increase or decrease the motion that is produced at the face of the converter. The booster is simply a tuned horn with a nodal mount point that allows the converter, booster, and horn assembly to be held for the purpose of delivering the ultrasonic energy to the plastic part. The boosters are rated by the amount of gain they increase or decrease the .0008 of an inch motion produced at the face of the converter. The typical booster gains are 0.6:1, 1:1, 1.5: 1, 2:1 and 2.5:1. These booster gains are used to put the converter, booster and horn assembly at the needed amplitude for a given application. The booster is sometimes color coded to ease identification of the booster amplification. The booster is attached to the face of the converter via a mechanical stud. The correct booster and horn combination is very important because amplitude is a critical variable in achieving a successful weld for a given application. The following decreases/increases can be obtained depending upon the booster used.

<u>Converter Amplitude (.0008)</u>	<u>*Booster Gain</u>	<u>= Output at Booster</u>
Purple Booster .0008	* 0.6: 1	= .00048 output at Booster
Green Booster .0008	* 1:1	= .0008 output at Booster
Gold Booster .0008	* 1.5:1	= .0012 output at Booster
Silver Booster .0008	* 2.0:1	= .0016 output at Booster
Black Booster .0008	* 2.5:1	= .0020 output at Booster

4. The ultrasonic **HORN** is a machined tool that resonates at the desired frequency. The horn is usually manufactured of titanium, aluminum or steel. The primary purpose of the horn is to uniformly transfer the ultrasonic energy to the work piece. The horn is usually made to match the shape of the part and to most efficiently transfer the ultrasonic energy through the part. Depending upon the size of the horn, there are various shapes of horn designs to increase or decrease the amplitude of the converter/booster/horn assembly. The horn is attached to the booster through the use of a mechanical stud.

5. The **ACTUATOR OR PRESS** is the pneumatic delivery system of the ultrasonic power. Its components consist of:

- Solenoid valve
- Cylinder or servo drive



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- Flow control valve
- Pressure regulator
- Air gauge
- Carriage to hold the converter/booster/horn assembly
- Slide mechanism to deliver the carriage with the converter, booster, horn assembly to the part
- Triggering mechanism to determine the amount of pressure delivered to the part before the ultrasonic energy is activated
- Communication ports to interface the press to the power supply
- RF port and cabling system to transfer the ultrasonic energy from the power supply to the converter

Ultrasonic welding systems can be as simple as on/off or more intelligent units providing greater control and monitoring. Both types of systems deliver ultrasonic energy to the work, but the intelligent systems provide the ability to weld by energy, weld by distance, monitor distances during welding, digitally monitor the pressure, electronically set the trigger force, monitor the trigger switch distance range and control and monitor the energy and forces seen by the system during welding. Pressure is a key variable in the delivery of ultrasonic power to the work. The dynamics and control of this variable are not well understood by many manufacturers that use the ultrasonic welding process.

6. The **POWER SUPPLY PROGRAMMER** is the control component that determines the sequencing, the duration, the delivery and monitoring of ultrasonic power applied to the work. On less sophisticated ultrasonic units, the duration of ultrasonic vibration is controlled primarily by time. Specifically, once ultrasonics is turned on or activated by a trigger switch, ultrasonic power continues to stay on until the duration of time is complete as established by the preset programmed time. With this type of programmer, there is limited control and monitoring of other system variables. With the advent of technology, the capability to expand the modes of welding and the monitoring of the welding process has grown dramatically. The more sophisticated units allow ultrasonic welding machines to weld by distance, energy, peak power and a combination of these control features. The sophisticated machines can also monitor time, energy, force, power, down speed, amplitude, and trigger distances with plus and minus acceptable limits. It is the power supply programmer coupled with other system devices that provides all the modern day control and information about the process.



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## CHAPTER TWO

### What Plastic Materials Can Be Welded

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The choice of plastic materials is generally driven by the requirements of the application. You choose the plastic based upon what best fits the need of the product and what the part is intended to do. However, the ability to weld plastic with ultrasonics is based upon a lot of factors including the plastic material itself, the joint design, material fillers; process variables prior to welding, part geometry, good part design practice, part size, amplitude and properly designed ultrasonic tooling.

The ability to weld dissimilar plastics is feasible if the material is an amorphous type of thermoplastic. However, all crystalline type resin materials are only capable of being welded to themselves. For example, you can weld nylon to nylon, but you cannot weld nylon to polyethylene.

Amorphous materials that are often compatible include:

- ABS welded to ABS/PC, PMMA, PC, ASA, NAS, SAN
- PMMA welded to ABS/PC, PPO, PC, ASA, NAS, SAN
- PC welded to ABS, ABS/PC, PMMA, PPO, PEI, PSU, PBT/PC
- PS welded to PPO, ASA, NAS, SAN
- ASA-NAS-SAN welded to ABS, PMMA, PPO, PS

We recommend that you test all dissimilar materials before proceeding with expensive tool designs and mold production. The table on the following page provides a reference for the acronyms above and how easily different materials are welded.



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<u>Material</u>	<u>Welding</u>	<u>Insertion</u>	<u>Staking</u>	<u>Near Field Welding</u>	<u>Far Field Welding</u>	<u>Ease of Staking</u>	<u>Trade name(s)</u>
<b><u>AMORPHOUS RESINS</u></b>							
ABS-Acrylonitrile Butadiene Styrene	30-70	20-50	30-80	1	1	1	Cycolac, Lustran
ABS/PC-ABS/Polycarbonate	70-100	50-70	80-120	2	2	2	Cycoloy, Pulse
ASA-Acrylonitrile Styrene Acetate	30-70	20-40	70-90	1	1	3	Centrex, Geloy, Luran
PC-Polycarbonate	50-90	40-70	50-90	1	2	3	Lexan, Calibre, Novarex
PEI-Polyetherimide	70-100	40-70		2	4	5	Ultem
PES-Polyethersulfone	70-100	40-70		2	4	5	Ultrason
PMMA-Acrylic	40-70	30-60	70-90	1	3	3	Acrylite, Plexiglass, Zylar
PPO-Polyphenylene Oxide	50-90	40-60	60-90	2	3	2	Noryl
PS-Polystyrene	20-40	20-40	70-90	1	1	4	Dylark, Styron
PSU-Polysulfone	70-100	40-70	90-120	2	3	3	Udel
PVC-Polyvinyl Chloride	40-80	20-50	70-100	2	4	2	Novablend, Ultrachem
SAN-Styrene Acrylonitrile	30-70	20-40	70-90	1	1	3	Lustran, Styvex
SBC-Styrene Block Polymers	50-90	30-50	80-100	2	3	2	K-Resin
<b><u>SEMI-CRYSTALLINE RESINS</u></b>							
PA- Polyamide (Nylon)	70-120	40-80	60-120	2	5	3	Celstran, Ultramid, Zytel
PBT-Polybutylene terephthalate (Polyester)	70-125	40-80	90-120	3	5	4	Celanex, Ultradur, Valox
PE-Polyethylene	70-120	40-80	40-120	2	5	2	Aspun, Clysar, Dowlex
PEEK-polyetheretherketone	60-125	40-80		3	5	5	Arlon
PET-Polyethylene terephthalate (Polyester)	80-120	40-80	90-120	3	5	4	Mylar, Rynite, Cleartuf
PMP-Polymethylpentene	70-120	40-80	90-120	4	5	2	TPX
POM- Polyacetal	75-125	40-80	50-100	2	3	4	Acetal, Celcon, Delrin
PP-Polypropylene	70-120	40-80	40-120	2	5	2	Astryn, Fortilene, Marlex
PPS-Polyphenylene sulfide	80-125	40-80		3	4	5	Fortron, Ryton, Supec

- The table above includes recommended amplitudes for welding, insertion and staking in microns (µm). To convert the values shown to inches, 25.4 microns = .001 of an inch.
- The amplitudes shown in the chart are for 20 KHz. To determine the amplitude requirement for 40 KHz, multiply the amplitude by 0.6, for 30 KHz multiply by 0.8 and for 15 KHz multiply by 1.2.
- Far and near field welding refers to the distance from the ultrasonic horn contact surface to the weld joint. Any distance in excess of 6.35 mm or .250" is considered far field.
- The ease of welding and staking/swaging guide is rated from 1 to 5 with 1 equaling the easiest and 5 equaling the most difficult.

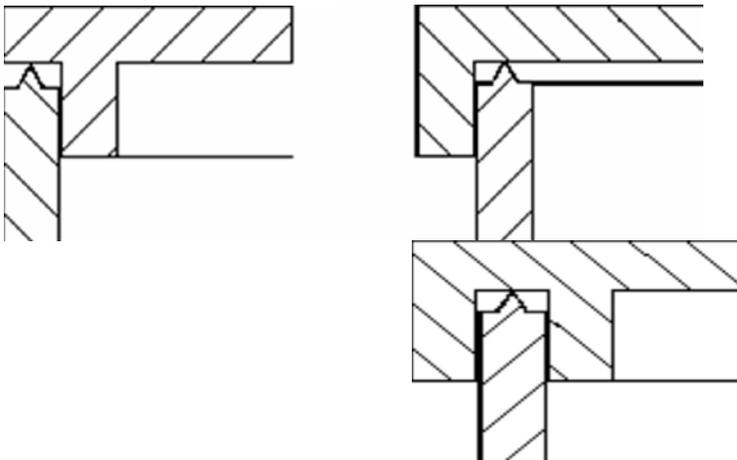
## CHAPTER THREE

### How to Design Parts for Ultrasonic Welding

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#### Energy Director Design

While it is possible to ultrasonically weld plastic materials without specific joint design details, the weld process is greatly enhanced by adding proven features that aid in the process. For example, without a means of alignment built into the joint it is impossible to predict where the parts will be positioned after welding. This is due to the nature of the vibratory process created by ultrasonic welding. This means of alignment is accomplished through the use of step joints, tongue and groove joints, pins and sockets, raised walls, ribs or other features that are used to keep the vibratory process under control to maintain the desired alignment of the parts after welding.



A feature that is shown in these joint alignment pictures is the molded-in triangular shape of material called an energy director. This molded-in triangular ridge of plastic is very effective at reducing the cycle time to achieve a weld and in compensating for non-uniform wall surfaces. The energy director design has been used for years as a means of focusing the energy to improve weld strength and reduce cycle time.

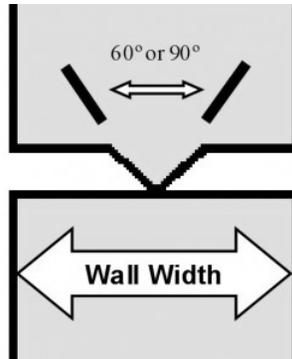
The energy director is typically placed only on one half of the part and runs along the surface to be welded. Without this energy director the weld quality would be suspect for many applications. For many applications the energy director can be interrupted and does not need to be continuous. The peak of the energy director should be sharp with a



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triangular shape formed from a 60° or 90° included angle. A 60° angle is generally used with crystalline materials and a 90° is used with amorphous materials. Material types by polymer structure are illustrated below:

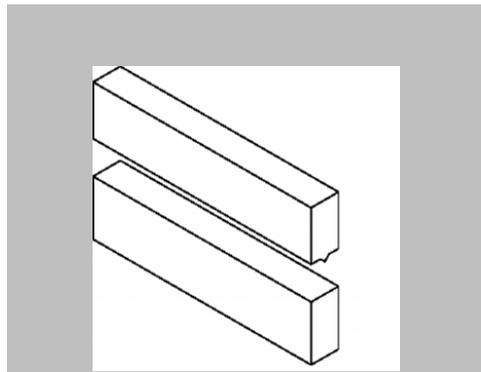


### Amorphous Resins 90° Angle

ABS-Acrylonitrile Butadiene Styrene  
ABS/PC-ABS/Polycarbonate  
ASA-Acrylonitrile Styrene  
Acetate  
PC-Polycarbonate  
PEI-Polyetherimide  
PES-Polyethersulfone  
PMMA-Acrylic  
PPO-Polyphenylene Oxide  
PS-Polystyrene  
PSU-Polysulfone  
PVC-Polyvinyl Chloride (Rigid)  
SAN-Styrene Acrylonitrile  
SBC-Styrene Block Polymers

### Semi-Crystalline Resins 60° Angle

PA- Polyamide (Nylon)  
PBT-Polybutylene terephthalate (Polyester)  
PE-Polyethylene  
PEEK-polyetheretherketone  
PET-Polyethylene terephthalate (Polyester)  
PMP-Polymethylpentene  
POM- Polyacetal  
PP-Polypropylene  
PPS-Polyphenylene sulfide



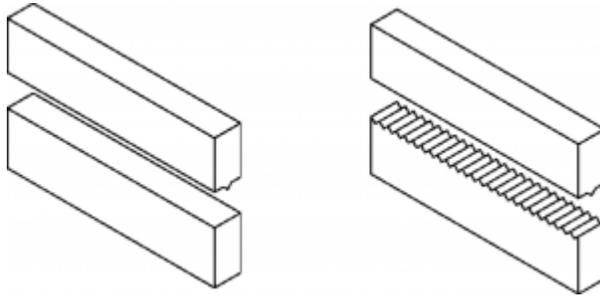
Depending upon the wall thickness and the application, the energy director typically varies in height in a range from .010 to .035 of an inch. The minimum height recommended is .010 for most amorphous materials, .020 for semi-crystalline materials and the amorphous polycarbonate material. While we've seen energy director heights of .060 of an inch tall, most energy directors don't exceed .035. Using a 90° energy director design, the height of the energy director is often determined by the width of the wall where the width of the wall is divided by eight, so that we have an energy director height equal to  $W/8$ . The energy director has typically been placed only on one half of the part and runs along the surface to be welded. Although it usually doesn't matter which of the parts to be welded incorporate the energy director, it is probably more common to find the energy director on the half that the horn contacts.



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## Criss-Cross Energy Director Design



Recent advancements with the energy director design have resulted in the use of the criss-cross energy director design. See the illustration above. The criss-cross energy director design utilizes the standard energy director shape where a triangular shaped bead of material is molded into the plastic wall on one of the parts to be welded. With the use of the criss-cross design, additional energy directors are added to the mating part, which increases the amount of material interaction. On the mating surface opposite the perimeter energy director, a series of perpendicular energy directors are molded-in to mate with the perimeter energy director. Better melt flow is achieved when the perpendicular energy directors are placed on the part contacted by the ultrasonic horn.

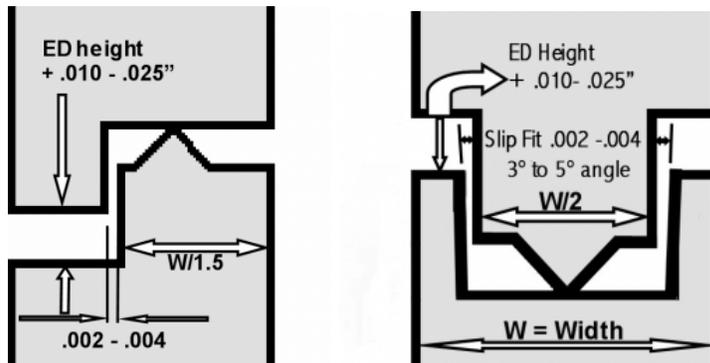
When a hermetic seal is desired these additional energy directors should take on a saw tooth pattern with each energy director repeating from the base of the proceeding energy director. Because there are energy directors on both mating surfaces, the energy director height on each half should be reduced to prevent excessive material flash during welding. Typically, it is recommended that the criss-cross energy director height be approximately 60% of the standard design.

The criss-cross energy director joint design is particularly effective when used in combination with a tongue and groove. Because of the increased material flow with the criss-cross energy director design, it is recommended that a tongue and groove joint be used to capture the additional plastic and contain the flash. This criss-cross design certainly increases the mold cost, but we've seen applications where the weld strength has far exceeded expectations and hermetic bonds have been achieved that might not have been achieved using the standard energy director on one mating surface.

**Step and Tongue and Groove Joint with Energy Director**

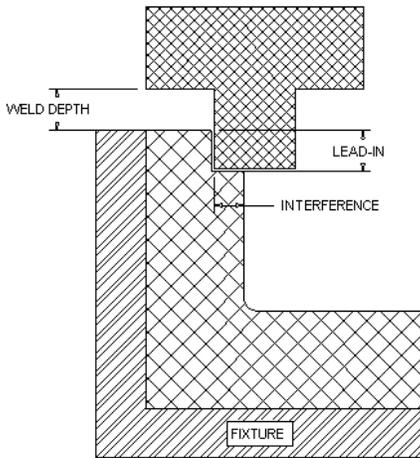
Without some designed in approach to controlling flash, an energy director by itself has the potential for molten material to flow beyond the wall creating flash outside the weld joint. If flash is a problem the use of step joints, tongue and groove joints, flash traps, raised walls and energy director placement have all been employed as a means of controlling the material flow.

Two types of joints commonly used to control flash and provide alignment are the step joint and the tongue and groove.



Both of these joints provide excellent flash control and the alignment necessary for a good ultrasonic weld joint design. The tongue and groove design provides the added benefit of being as an excellent reservoir for the melted material. This pooling of plastic material helps contain the material and increases the likelihood of a hermetic seal. The additional height of .010 to .025 inches added as a gap around the periphery of the part provides a shadow line that helps to hide variation with part tolerances and melt flow during the ultrasonic welding process. This is a feature that we highly recommend because it helps to eliminate potential flash caused by the mating perimeter surfaces touching and it becomes imperceptible to the eye when the weld melt down is not perfect.

**Shear Joint Design**



Guidelines for Shear Joint Interference		
Maximum Part Dimension	Interference per Side (Range)	Part Dimension Tolerance
Less than 0.75" (18 mm)	0.008" to 0.012" (0.2 to 0.3 mm)	± 0.001" (± 0.025 mm)
0.75" to 1.50" (18 to 35 mm)	0.012" to 0.016" (0.3 to 0.4 mm)	± 0.002" (± 0.050 mm)
Greater than 1.50" (35 mm or larger)	0.016" to 0.020" (0.4 to 0.5 mm)	± 0.003" (± 0.075 mm)

Although the energy director design can work satisfactory for welding semi-crystalline plastic materials, there are circumstances that warrant the use of another type of joint design. When welding materials like nylon, polyacetal, polyester, polyphenylene sulfide, polypropylene or polyethylene and a hermetic seal is required, the shear joint has proven beneficial for many applications. Therefore, the shear joint is frequently used when a hermetic seal is required on semi-crystalline plastic materials. When a hermetic seal is not required, the shear joint can be interrupted and does not need to be continuous.

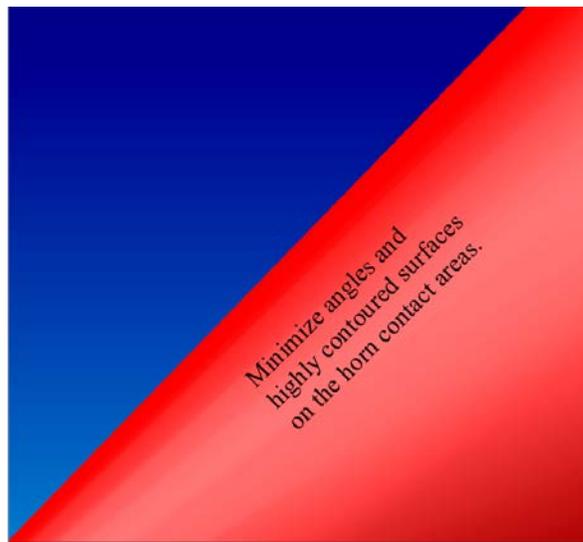
The reason for using a shear joint relates to the way the semi-crystalline material flows when introduced to heat. These types of plastics have a very sharp melting point and once the heat is reached to create a melt flow, the material immediately becomes liquid and flows rapidly. Semi-crystalline plastics also re-solidify within a small temperature variation. When an energy director is used with semi-crystalline plastics, the molten material gets exposed to a lower temperature when outside of the melt zone and can re-solidify before the desired bond is achieved. Because the melt zone of a shear joint is held along a vertical wall, the temperature variation is reduced within this melt zone since the material is not easily exposed to the surrounding air.

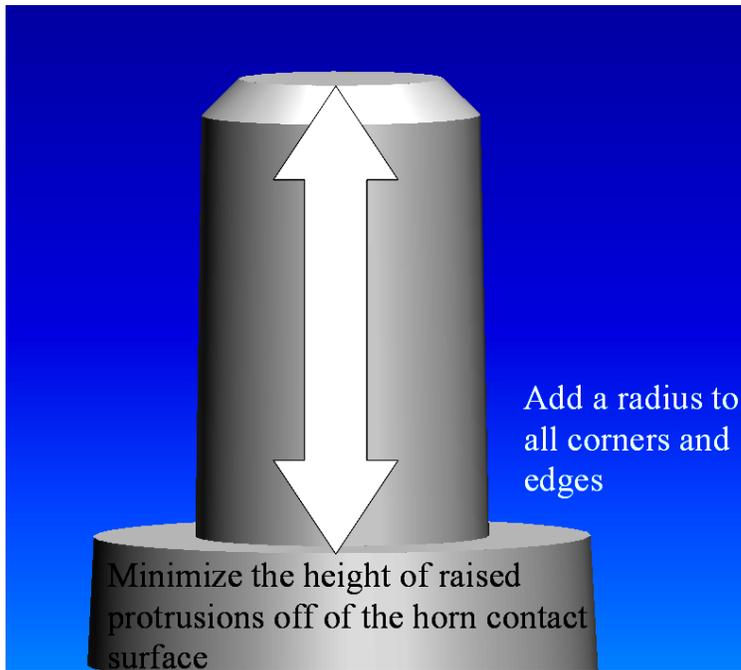
The shear joint is not the answer for all applications. We recommend caution when applying the shear joint to polypropylene or polyethylene due to the lack of rigidity with these materials. The lack of stiffness with these materials often results in pushing past the shear joint instead of melting and welding the material at the joint interface. The shear joint requires high tolerance, so we suggest you use caution incorporating a shear joint design on larger parts or irregularly shaped parts. The shear joint should not be used when a part is larger than 3 1/2" in diameter or has sharp corners or unusual shapes.

## Other Design Concepts to Consider

It is important to design the part so the horn has as uniform of contact surface as possible. The key is to remember that the ultrasonic energy has to travel through the material to the joint interface and cause the materials to vibrate against each other to create a frictional weld. Anything in the path of this energy or anything that minimizes the energy transfer can impact the weld. Of course, the preference would be to see a nice flat horn contact surface with the minimal amount of distance from the horn contact to the weld joint, but this is generally not practical in today's highly competitive marketing environment. Also, there is no doubt that the advent of CAD has improved the ability to add contours and shape to the molded plastic parts. However, there are some things that should be considered to improve your odds of having a successful ultrasonically welded product.

- Allow the horn to contact over the joint. Don't put features on the part that prevent the horn from being over the energy director or shear joint. A cored side hole in a part that is directly above the energy director will effect the weld under the hole. Don't include steep angles over the weld joint. The energy does not travel effectively in a diagonal dimension and large angles or deep bends don't facilitate the energy transfer.
- Try to keep the horn contact surface to the weld interface dimension at a minimum. Some materials can transfer the energy further than other materials, but all generally all materials work best the closer the horn is to the joint interface.





- Don't have large protrusions on the part that the horn contacts. The horn is a tuned element and anything that protrudes above must be cleared for in the horn. Sometimes the protrusions get so tall it is not possible to build the horn. Any protrusion or appendage that extends from the part should have a generous radius to minimize part damage.

- Add a radius to all sharp edges.
- Typically it is best to design the part so the horn can contact the lighter part.
- Add ribs to thin walled parts to prevent deflection and increase rigidity.
- Many times it is not necessary that the entire periphery of the part is welded. In these situations you can consider welding at interrupted locations at different points on the part.
- Don't forget to incorporate alignment features in the part. If the part joint does not include step or tongue & groove alignment features, add tabs or pins and sockets to align the parts before and after welding.
- The addition of fillers to the material can impact the weld. Rubber modifiers generally result in poorer welds. A 20% fill of glass and talc usually improves the rigidity of soft plastic materials and enhances the energy transfer to the joint. Any filler that adds lubricity to the material can impact the frictional characteristic needed to bring the material to melt flow and can result in poorer welds.
- Try to keep regrind to a minimum.



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## CHAPTER FOUR

### What Frequency?

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#### **HOW SHOULD THE CORRECT FREQUENCY FOR THE APPLICATION BE DETERMINED?**

Manufacturers of ultrasonic equipment make ultrasonic welders that operate at different frequencies to provide machinery that best meets the requirements of a given application. The most common frequencies for ultrasonic welders are 15, 20, 30 & 40 kHz, but some manufactures have selected to produce machines at frequencies that are slightly different, such as 19, 28 and 35 kHz.

The process of determining the correct frequency to use for a given application is often one of trial and error, but there are some excellent guidelines that can point one towards the best selection. One key element for choosing the appropriate frequency relates to the size of the ultrasonic horn. The ultrasonic tooling manufacturer has to design the horn to resonate at the frequency generated by the machine or it will not work. In essence, you have a large tuning fork that must operate at the machines output frequency or it won't function. There are horn size limitations for different frequencies. It is also necessary to produce horns that separate any secondary frequencies from the primary frequency, so the machine knows the correct frequency on which to run. Part size alone can be the deciding factor on what frequency to select.

The 20 kHz frequency is the most common frequency found in industry for plastic welding. The 20 kHz frequency can weld a broad range of plastic part sizes and perform other applications like staking, swaging, cutting, fabric sealing and insertion that can be accomplished with the ultrasonic process. At 20 kHz, parts have been welded using a single tool up to 9" x 12" and as tiny as 1/8" in diameter. For insertion of metal into plastic components, 20 kHz equipment is the most common frequency used as the transducers (converters) are very rugged at the 20 kHz frequency range and can withstand the impact of a vibrating horn contacting a metal insert. Additionally at 20 kHz, equipment manufactures make high wattage equipment with the capability of installing metal components up to 1/2" in diameter. When staking a plastic stud or spot welding two plastic pieces together, 40 kHz equipment may be the most prevalent frequency used with these types of applications. However, it is not uncommon to see 20, 30 and 35 kHz used for ultrasonic staking and spot welding. 40 kHz is also the most common frequency used



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for welding small parts, parts with electronic components enclosed, parts with appendages attached that might be damaged during the ultrasonic process and applications that just require smaller sized equipment. The approximate diameter of a 20 kHz converter is 3 inches, while a 40 kHz converter is 2". Additionally, the length of a 20 kHz ultrasonic ½ wave horn is close to 5 inches and the length of a 40 kHz ultrasonic ½ wave horn is close to 2 ½ inches. This smaller size allows the 40 kHz equipment to be used in closer proximity making the use of 40 kHz equipment common in machines having space constraints and multiple ultrasonic converter/booster/horn assemblies.

30 kHz provided a bridge between 20 and 40 kHz that allows more power and amplitude to be delivered than 40 kHz, but still less amplitude and power than 20 kHz. For example, say you have a part that can be welded by 20 kHz, but internal components are being damaged during the process. You decide to try 40 kHz, but you find your part is too large for the tool maker to produce a good running ultrasonic horn that produces sufficient amplitude needed to weld the part. You may also find that your joint interface is such that the 40 kHz equipment can not sufficiently transfer the energy the required distance to create the melt flow needed at the joint interface to weld the parts. It is also possible that you might discover that 40 kHz equipment simply does not have the power output needed to make a good weld. 30 kHz is a frequency that provides a solution that can fill a gap when 20 or 40 kHz proves unsatisfactory for welding the part. 30 kHz provides greater amplitude and power than 40 kHz, but less amplitude and power than 20 kHz.

Building a horn for ultrasonic welding is not totally unlike building tooling for injection molding machinery. Different tonnage injection molding machines require different size molds. Different ultrasonic frequencies allow the production of different size horns for welding different size parts. Although the 20 kHz frequency can weld parts up to 9" x 12" with a single horn, this is atypical for 20 kHz equipment. The horn design that can be manufactured to operate at 20 kHz is limited for welding a part this size. Also, welding a large part of this size using 20 kHz is usually limited to ABS or Styrene materials. Different plastic material to be welded at this size will generally lead one to choose 15 kHz equipment. Large horns can be produced to run efficiently at the 15 kHz frequency which allows for welding of larger parts, parts with more irregular geometries, parts that have a substantial difference from the horn contact surface to the joint interface and more difficult to weld materials.



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## **HOW DOES THE TYPE OF TERMOPLASTIC TO BE WELDED AFFECT THE FREQUENCY NEEDED FOR ASSEMBLY?**

The material melt flow at the joint can be influenced by the welder frequency and how the energy transfers through the material at a given frequency. This vibratory transfer of energy can be different for varying part geometries, distances to the weld joint, plastic material used and the amplitude needed to create a weld.

The higher the frequency, i.e. 40 kHz, the more the energy is dissipated or attenuated in the material resulting in a reduction of distance the mechanical vibrations will travel in the material through the part to the joint. The lower the frequency the further the energy travels through the part before it is attenuated. In some difficult to weld materials at high frequencies the mechanical vibrations created by the ultrasonic energy can be completely dissipated near the top surface where the horn contacts. So the distance from the horn contact surface to the weld joint will impact the frequency needed to weld. Some plastic materials transfer the energy more readily than other materials, so it becomes a combination of the type of material and the distance to the weld joint to determine if a specific frequency will work for a given application.

As a general rule, the chemical composition of the material to be welded will greatly influence the distance the ultrasonic energy will travel in the material. The amorphous type plastic materials usually allow the mechanical energy to travel further down the material from the horn contact surface to the weld joint. Amorphous materials are plastics with generic names like polystyrene, ABS – acrylonitrile butadiene styrene, acrylic and polycarbonate. Crystalline resin type plastic materials usually attenuate or restrict the mechanical vibrations reducing the distance the energy travels from the horn contact surface to the weld joint. Crystalline materials are plastics with generic names like Nylon – polyamide, polyethylene, polyester and polypropylene.

The distance to the weld joint from the horn contact is defined as near field and far field. For years, a ¼” or less has been defined as a near field weld condition and more than a ¼” of distance has been defined as a far field weld condition. Honestly, this definition should be revised to be material and frequency specific, but to my knowledge no one has undertaken this task, so for now we will use this reference. Because the ultrasonic energy is attenuated in plastics to a greater degree at higher frequencies than at lower frequencies, the distance to the weld joint from the horn contact surface will guide the feasibility of using a particular frequency. For example, let’s say a part is ABS and the distance to the weld joint is 3 inches from the horn contact surface. It is questionable that a higher frequency 40 kHz welder could transmit the energy through the ABS material over a 3 inch distance and create a good weld. Since frequency determines the distance



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the energy travels in the material, for this part the most logical choice would be to consider a lower 15 or 20 kHz frequency welder. However, let's say an ABS part has a distance to the weld joint of ½" from the horn contact surface. Even though the joint distance is considered far field, due to the ease at which ABS transmits ultrasonic energy, it would be feasible to consider 30 or 40 kHz for a part at this weld distance if the part is small. However, for another example, let's say the material is a crystalline polypropylene material and the distance to the weld joint is ¼". At first glance, it might appear that all frequencies could be considered since the weld joint is a near field condition. However with PP crystalline material, the energy is absorbed so rapidly by the material it is questionable that a good weld could be achieved using a higher 40 kHz frequency.

As one might imagine, the combination of material, part design and joint design is exponential, but hopefully the guidelines of material type and the distance from the horn contact surface to the weld joint help to direct one towards a frequency choice that is suitable for the material and the part design. In most ultrasonic welding applications, it is a combination of the part size, the part geometry, the material used and the distance from the horn contact to the weld joint that determines the best frequency.



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## CHAPTER FIVE

### What Horn & Booster?

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#### **IN WHAT WAYS DOES THE HORN'S METAL TYPE AFFECT THE ASSEMBLY PROCESS?**

Most ultrasonic horns are manufactured using specific grades of aluminum and titanium; however D2 steel and CPM steel are also used for some specialty applications. As a first step to determining a horn metal to be used, one must first analyze how much amplitude is required for the application. Based upon the plastic material and the type of application, the range of required amplitudes needed are broad. The size of the horn, horn cost, horn wear and the quantities of parts to be assembled must all be considered when selecting a horn metal type for the assembly process.

At 20 kHz most ultrasonic welders produce approximately 20 microns or .0008 of an inch movement at the face of the converter when activated by the ultrasonic power supply. The face of the converter is expanding and contracting 20,000 times per second for a total displacement of 20 microns. There are not many applications for plastic assembly that can use such a small amount of motion and effectively melt the material. The two other components used with the converter to increase the amplitude level to a more workable level are the booster and the horn. As stated in the equipment component section above, the booster is simply a tuned horn with a nodal mount point that allows the converter, booster, and horn assembly to be held for the purpose of delivering the ultrasonic energy to the part. The boosters are rated by the amount of gain they increase the 20 micron motion produced by the converter. The typical booster gains are .6:1, 1:1, 1.5: 1, 2:1 and 2.5:1. These booster gains are used to put the converter, booster and horn assembly at the needed amplitude for a given application. Booster materials are aluminum or titanium. Choosing the appropriate booster is dependent upon the application and the gain of the horn.

The ultrasonic horn is designed to fit the part being welded. However, another very important element to the horn design is building gain into the horn, so the converter, booster and horn assembly have sufficient amplitude to perform the application. Building gain into the horn adds stress to the tool and plays a role in determining what horn material should be used.



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As previously stated, the amplitude required to perform a specific function varies tremendously with the application. Fortunately, most applications have a range of amplitudes that will work for the assembly process.

**SEE THE CHART ON PAGE 6 ILLUSTRATING THE RECOMMENDED AMPLITUDES FOR ULTRASONIC WELDING, INSERTION & STAKING.**

The reason that this amplitude reference information is important is it provides the guidelines for the type and style of horn that needs to be built to achieve the amplitude levels required for the application. Build a horn with insufficient gain and the application will not work. Put too much gain in the horn and you add stress to the tool reducing the life of the horn. A horn is expanding and contracting at a rapid rate and the further the horn is expanded and contracted, the greater the potential for the horn to fatigue. Take a rubber band and expand and contract the rubber band. The greater the rubber band is stretched and the more frequently it is stretched, the more likely it is to break.

What horn material should be used? Because it is important to reach high amplitude levels for some applications, it is absolutely essential in these situations to use titanium material instead of aluminum for the ultrasonic horn. The fatigue strength of titanium is approximately 2.3 times that of aluminum. At very high levels of amplitude, the aluminum horn might not last very long. However, at lower levels of amplitude the aluminum horn can last for a very long period of time. An aluminum horn will cost substantially less than a titanium horn. The cost of titanium material compared to aluminum material is significant. The increased machining time required to produce a titanium horn versus an aluminum horn also increases cost to the end user. There are excellent benefits for using aluminum horns where the application allows. However, there are times one simply cannot use aluminum and titanium is the appropriate material due to the application requirements.

D2 steel is very prone to fatiguing at ultrasonic frequencies where high gain levels are required for the application. Fortunately, the application where D2 tool steel is most commonly used for ultrasonic assembly is installing metal components into plastic parts and this application does not require high amplitude levels. Since ultrasonic metal insertion is a high wear application, D2 steel often proves to be the material of choice for high production insertion jobs. This is not to say that titanium will not work for insertion applications, but one will see improved tool wear when using D2 steel horns for metal insertion installations. For some high wear welding applications, where the plastic material is particularly abrasive to the horn face, CPM steel has also been used. Although the CPM steel can run at amplitude levels exceeding aluminum, it also has a



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higher resistance to acoustical energy transfer than aluminum or titanium. So, CPM is not acoustically as efficient as titanium or aluminum.

There is usually a tradeoff regarding which metal material to use for manufacturing horns. Aluminum is the most acoustically efficient, followed by titanium and then steel, but aluminum has the drawback of increased fatigue failure and reduced wear resistance. FEA analysis now allows the horn toolmaker to use 3D computer modeling to identify stresses and predict performance of the ultrasonic horn. This technology lets the horn builder identify potential issues and engineer the horn to reduce failures. Information such as material, maximum gain ratio for the material, the speed of sound in the material, fatigue strength and acoustical impedance can all be implemented in the FEA designed horn to optimize the tool design. FEA gives the horn maker the ability to analyze different materials for a specific design and determine the safe level at which an ultrasonic tool can operate without reaching its fatigue limits. A virtual model can be produced that allows the ability to see how the horn will operate under real life conditions. The tool designer can also check amplitude uniformity across the face of the horn and make design changes to improve the efficiency. This advance in design and analysis technology provides the horn maker with the tools to help select a horn material that will function well while considering cost and projected use of the tool.

## **WHAT ATTACHEMENTS CAN BE ADDED TO ULTRASONIC HORNS; IN WHAT CASES WOULD THESE ATTACHMENTS BE NECESSARY?**

There are situations when it is necessary to add other components to an ultrasonic horn. One of these situations occurs when the mechanical vibrations created from ultrasonic oscillation causes damage to the part at locations outside of the weld area. Thin top covers might diaphragm and cause a hole or mark to appear on the part. A boss or appendage without adequate radii might detach when the part is ultrasonically vibrated. In situations like these it is not uncommon to add a nodal plunger to the horn. A nodal plunger can be added by attaching a mount to the nodal point of an ultrasonic horn. The nodal point of the horn is in theory the place on a horn where there is no vibration. This nodal position on the horn exists in all horns and provides an excellent point of attachment for secondary devices.

By adding a nodal attachment, features can be added to the horn that will contact the part and isolate the vibratory energy at the problem area. This damping effect has been very effective at isolating the energy at a local position still allowing the horn to vibrate and create a weld at the joint. By isolating or damping the energy, the damage is resolved.



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Another reason for adding a nodal attachment is to serve as a clamp. This can be particularly effective with a spring loaded nodal plunger. The nodal plunger comes in contact with the part to be held in place during the ultrasonic process and because the hold down is spring loaded, the horn continues to travel to the work piece allowing the assembly operation to occur.

One other type of attachment that is found on horns is the addition of a vacuum feature. The vacuum line is usually attached to the horn at the nodal point and provides a feature to hold a part in position before the horn is delivered to the part piece to be welded. While this feature can be used as an alignment device, it is preferable to have the part designed so the alignment occurs within the part and nothing is attached to the horn before it descends to weld the part.

Another type of attachment added to an ultrasonic horn is the various types of coatings added to the face of the horn to reduce part marking and increase wear resistance. The types of coatings that have been used for coating ultrasonic horns are broad, but the more typical coatings seen are chrome, anodizing and carbide coating. The chrome and anodized coatings are used with aluminum horns to prevent oxidation and reduce part marking. The carbide coating is used with titanium to improve wear resistance when welding abrasive materials.



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## CHAPTER SIX

### What Fixture?

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**WHAT ROLE DO ULTRASONIC FIXTURES PLAY IN THE SUCCESS OF THE WELD? HOW DO MATERIALS USED TO CREATE THE FIXTURES AFFECT THE WELD? WHAT ATTACHMENTS CAN BE ADDED TO ULTRASONIC FIXTURES; IN WHAT CASES WOULD THESE ATTACHMENTS BE NECESSARY?**

The use of CAD/CAM technology has greatly improved the manufacturing of contoured fixtures to support the part during ultrasonic assembly. Exact mirror replicas of the part can be created to provide excellent support to the part. Due to complex contours seen on many parts, it is recommended that the horn and fixture be purchased as a set, so proper alignment is achieved between the two. The fixture used for ultrasonic assembly is often overlooked, but usually very critical to the success of the application.

The use of a fixture that is not properly designed will usually result in very poor welds or no weld at all. Typically you want the fixture to support the part half to be welded that has the deepest draw. The horn will contact the other part to be assembled, so that the distance from the horn contact surface to the weld joint is minimized. The primary purpose of the fixture is to hold the part secure, in position and in alignment to the ultrasonic horn that will descend upon the assembly. It is important to support the bottom of the part to prevent it from deflecting under the pressure applied by the ultrasonic welder. If the part does not fit correctly, alignment can be impacted and energy that is needed for the weld can be dissipated into locations not necessary for the weld. A sloppy fit can actually create a condition in which the parts vibrate in unison instead out of phase with each other. It is preferred that the part in the fixture be held sufficiently to allow the mating piece to vibrate against the fixtured part and create a melt flow. If the parts vibrate in unison during ultrasonic vibration, the frictional activity is decreased resulting in less melt flow.

Many different types of materials have been used to build fixtures for ultrasonic assembly including plastics, stainless steel, tool steel, aluminum, cork, poured urethane and silicone rubber. All of these can play a role depending upon customer's needs, but the most common fixtures include aluminum, steel and poured urethane.



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Poured urethane fixtures are frequently used for supporting rigid amorphous plastic parts. Urethane fixtures are especially advantageous for providing good support with rigid parts and eliminating or reducing part marking that can occur during ultrasonic assembly. Urethane fixtures have also been used successfully as a part support for insertion and staking applications. Urethane fixtures have been used successfully for insertion applications with 8-32 or smaller inserts and staking applications with boss diameters less than 1/8 of an inch. Historically, urethane pours were not uniform and often used too much urethane in areas for supporting the part. Due to the resiliency of urethane material, this inconsistency of the poured urethane would result in varying support at different locations around the part. The advent of new thin poured urethane fixtures provides good consistent support and a resistance to burning that was seen with the thicker poured urethane fixtures that were used in previous generations of ultrasonic welding. The use of the thinner poured urethane fixtures can be advantageous to welding, reduce part marking and provide good support to the part allowing for good transfer of ultrasonic energy to the part and not the fixture.

The most commonly used nest material is aluminum. Aluminum provides good rigid support and can easily be reshaped if the plastic parts come in oversized. It is used for crystalline and amorphous plastic parts. Aluminum is almost always the material of choice for supporting parts made of crystalline type plastic materials. Aluminum fixtures may need to be hard coated if the plastic material includes abrasive fibers, but the material is generally clear anodized or chrome plated to prevent part marking. Part marking is a real concern with a rigid aluminum nest, particularly if the part does not fit the nest well. If the contours don't match, the vibratory energy can result in the rigid fixture marking the plastic part creating an unsightly scar.

Steel is also used as a fixture choice for ultrasonic assembly. It is often chosen for its improved wear characteristics, particularly when welding highly abrasive materials. It is also selected for use as anvil fixturing to provide knurling and various stitch patterns for textile weld and slitting applications. No coating is required if the material is stainless, but black oxide coating is frequently used for other tool steels.

The deciding choice for fixture materials usually comes from the type of support required and the type of weld joint used. The fixture usually supports the lower part up to the parting line to prevent part marking during the ultrasonic assembly process. If the part has a deep draw it is probably advantageous to use aluminum material to improve loading of the part into the nest and unloading of the part out of the nest. On crystalline material applications, a joint called a shear joint is frequently employed which causes the part to expand at the weld joint as the material melts. With this type of joint, you would want to make sure the fixture material is very rigid to suppress deflection and make sure the melt



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occurs along the vertical wall of the shear joint. Due to the resiliency of urethane material, it would not be a good material choice for a shear joint welding type of application. When a part is welded using an energy director joint where there is no force against the outside wall, most of the support is needed on the part in the area under the energy director. With the energy director joint the most common choices are aluminum, stainless steel and poured urethane.

The fixture material choice will also affect how the plastic material flows at the joint interface. A soft resilient type of material will create a different flow rate than a rigid metal nest. Different fixture materials will create various frictional reactions at the weld joint. An experienced ultrasonic tool maker can assist with choosing the appropriate fixture material. Most of the time they will be right based upon their application experience and exposure to the broad choice of plastic material choices used to manufacture plastic products.

Most fixtures include a slotted aluminum subplate for mounting to a welder base or automation system. The slotted subplate allows for ease of alignment between the part and the ultrasonic horn. Many fixtures will incorporate leveling features on the aluminum subplate to adjust the nest if the fixture is not parallel to the machine and the ultrasonic horn.

Just about any type of attachment can be added to an ultrasonic fixture to improve alignment, enhance part loading and unloading, eject the part, clamp parts, provide slides to move the part or the fixture, etc... Servo and pneumatic drive motion control systems have also been used as fixture attachment devices to lift the part to a stationary vibrating ultrasonic horn.

Common used fixture attachments include the use of clamps and slides. A clamp is often used to provide support to the part, but allow a split fixture to open wide for part loading. This clamp approach allows the fixture to provide excellent support at the joint, but still open up for part loading. This fixture clamping approach is often necessary due to limited stroke capacity of the ultrasonic weld machine. Slides are also incorporated into fixture designs to move the part into a position out from under the ultrasonic horn to allow for part loading. Slides are also used for welding at different locations on the part, to move a fixture component into position for improved support and to scan along a weld seam. Slides have been used to move a part along an X-Y axis to aid in installation of multiple inserts or to allow the horn to stake posts at multiple locations. With the use of slides one finds other fixture attachments like stops and detents to control the motion position. The use of clamps and slides can be activated manually or automatically depending upon requirements for volume, ease of use and cost considerations.



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Mechanical part ejection attachments are often added to fixtures to enhance part removal after the ultrasonic welding process. This eject feature is generally required if there is a deep draw to the part or the part imbeds itself into the nest during the assembly process. The mechanical eject attachment components can be as simple as a manual lever lift or a more complex like a lift driven by a pneumatic cylinder. Smart fixtures with plc controls have been used as a fixture attachment to provide sensors to ensure part placement before the weld cycle and to activate automatic part ejection after the weld cycle. It is feasible to envision that these smart fixtures could also incorporate part loading.

Customers that need rapid tool change are constantly requesting quick change fixtures. For quick change tooling, the use of dowel pins and bushings are commonly found fixture attachments. Coupled with quick tool change features for the ultrasonic transducer, booster and horn assembly, the end user has the capability to change jobs much faster providing a substantial reduction in setup time.

## Conclusion

Please know that the information presented are guidelines only intended to assist with analysis of your welding process. Each application is unique and requires testing to know that ultrasonic welding of your part functions as intended.

During the writing of this paper, we realized that there is much we can continue to share that we know and continue to learn about ultrasonic assembly. We have many other topics that we want to review in more detail and pass along to users of the process. We encourage you to come back periodically to download and re-read the *Guide to Ultrasonic Welding* as it is our intent to continue to increase and improve the content of this guide. You have our permission to reproduce this guide and share its contents with your colleagues. Thank you for taking your time to read this material!

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### Endnotes:

1. Some of the content above was reprinted with permission from **Plastics Decorating**, today's news source for all plastic decorating and assembly solutions. The April/May 2013 issue included an article "*Ultrasonic Horns Determine Weld Success*" written by Gary Clodfelter of Plastic Assembly Technologies, Inc. This article can be found on the Plastics Decorating website, [www.plasticsdecorating.com/stories/052013/assembly.shtml#Ufbwgm\\_D-Uk](http://www.plasticsdecorating.com/stories/052013/assembly.shtml#Ufbwgm_D-Uk).