The German Electrical
and Electronic
Manufacturers' Association

ZVEI:
Elektroschweißgeräte

Ultrasonic assembly of thermoplastic mouldings and semi-finished products

Recommendations on methods, construction and applications

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Preface

The recommendations on "Ultrasonic assembly of thermoplastic mouldings and semi-finished products" were drawn up by a working party composed of manufacturers of ultrasonic welding equipment, producers of raw materials and users, under the auspices of the German Electrical Manufacturers Association (ZVEI).

Ultrasonic techniques for the joining of thermoplastic mouldings are widely used in industry. As experience has been acquired in this field it was felt that it would be beneficial to compile the existing knowledge in the form of a guideline. So as not to confuse the picture, exceptional applications of the technology have been disregarded.

The recommendations are intended to be an aid in the application of ultrasonic techniques for the joining of plastics and a contribution to the clarification of problems and the avoidance of mistakes.

In the case of critical applications it is recommended that contact should be made with the manufacturers of the ultrasonic equipment or the producers of the raw materials.

All the information has been given according to the best knowledge of those concerned. No liability whatsoever can be assumed, however.

Participating firms:
BASF AG, Ludwigshafen
Bayer AG, Leverkusen
Robert Bosch GmbH, Stuttgart
Branson Schallkraft GmbH, Heusenstamm
Herfurth GmbH, Hamburg
Herrmann Ultraschalltechnik GmbH, Karlsbad-Ittersbach
Hoechst AG, Frankfurt/M
KLN-Ultraschall GmbH, Heppenheim
Nederlandse Philips Bedrijven B.V., Eindhoven
Siemens AG, Erlangen, München

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1. General (Basic points)

The range of mechanical vibrations which can be heard by the human ear lies between frequencies of 16 Hz and 16,000 Hz. The non-audible frequencies below 16 Hz are known as infrasound and those between 16,000 Hz and 10^{10} Hz as ultrasound (US). Frequencies above 10^{10} Hz are known as hypersound. The frequency is the number of vibrations per second.

Ultrasonic vibrations are used in a wide range of techniques such as purifying, metal welding, machining, metal forming, soldering, materials testing, locating, diagnosis, therapy, signal transmission, etc. As a result of the increasing use of thermoplastics in the last two decades ultrasonic joining techniques have developed into an important process in joining technology. Ultrasonic plastics welding and riveting in particular have been widely applied in the fields of electrical equipment, components and the motor car and textile industries. According to the area of application ultrasonic welding equipment with frequencies between 20 and 50 kHz is used.

Commercial electrostrictive and magnetostrictive transducers almost always vibrate longitudinally, which means that the sound-emitting surface of the oscillator vibrates sinusoidally around the position of rest of the surface.

Figure 1 shows a longitudinal wave. With this kind of wave the direction of propagation and the direction of vibration coincide. The distance between two equal vibrational states is denoted by the symbol λ (wavelength).

λ can be calculated from the following equation:

$$\lambda = \frac{v}{f}$$

λ = wavelength
v = sound velocity of the material
f = frequency

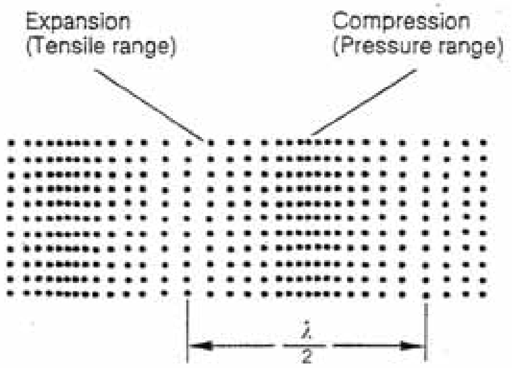


Figure 1: Longitudinal wave

Pure longitudinal waves only occur in spatially unlimited media or in dimensions $\gg \lambda$. On account of the geometrical shape of the energy conductor (transformer, sonotrode) in ultrasonic equipment used in joining technology there is usually a mixture of transverse and longitudinal vibrations. In the case of transverse waves the direction of vibration is perpendicular to the direction of propagation (fig. 2).

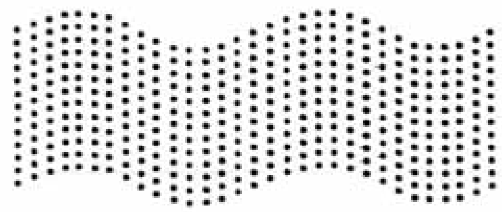


Figure 2: Transverse wave

The mixed type which occurs is known as a dilational wave (fig. 3).

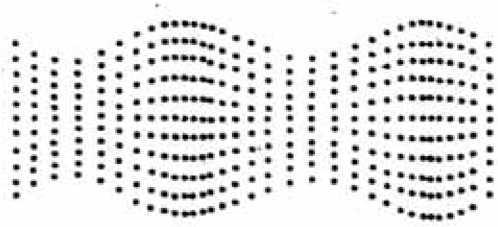


Figure 3: Dilational wave

In the compression range a thickening takes place and in the expansion range (greatest amplitude) a dilution takes place.

An upright wave is formed as a result of the reflection of the vibrations produced by the ultrasonic transducer on the sound-emitting end surface of the mechanical resonance unit of the vibrational system. The position of the nodal point of vibration (zero longitudinal amplitude) and of the loop of oscillation (maximum longitudinal amplitude) remains constant. The mechanical resonance unit is therefore usually positioned at the nodal point of vibration. The work surface of the sonotrode is in the loop of oscillation, in other words at maximum longitudinal amplitude.

The emergence of uncontrolled flexural waves (fig. 4) is to be avoided in the design of sonotrodes.

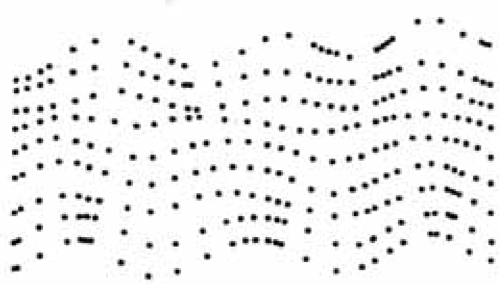


Figure 4: Flexural wave

2. Methods

2.1 Ultrasonic welding of mouldings and semi-finished products made of thermoplastics

In accordance with DIN 1910, part 3, and DIN 16960, sheet 1, the mouldings are heated and plasticised and, as pressure is applied, welded at the joining surfaces or interfaces as a result of the effect of ultrasound, preferably without any welding additive being used. The necessary force is produced manually or mechanically. The force and the direction of vibration are generally at right angles to the joining surfaces. Welding can be carried out in cycles or continuously.

In ultrasonic welding the electrical vibrations in the ultrasonic range produced by the generator are converted in the transducer (converter) into mechanical vibrations of equal frequency and transmitted to the work pieces via the transformer (booster) and the sonotrode. The generator, the transducer, the intermediate piece and the sonotrode work in resonance.

The heating in the joining area takes place as a result of the absorption of the mechanical vibrations, the reflection of the vibrations in the joining zone and the interface friction of the joining surfaces.

Of key importance for obtaining a good reproducible welding quality are, along with the right choice of ultrasonic welding equipment, the effects of the thermoplastics, which are connected with the nature of the raw materials, the manufacturing conditions and the constructive shaping of the mouldings (work pieces), the design of the joining surface and the ability to work with optimised welding parameters.

2.2 Further possible uses

The methods described in greater detail under point 8 operate according to the same principle as the ultrasonic welding of thermoplastics (point 2.1).

- ☐ near-field welding (direct ultrasonic welding), point 8.1.1
- ☐ far-field welding (indirect ultrasonic welding), point 8.1.2
- ☐ welding with inserted sealing, point 8.1.3
- ☐ welding of mouldings – injection-moulded, extruded, blow-formed, thermoformed – with semi-finished products or sheet, point 8.1.4
- ☐ welding of mouldings – a combination of injection-moulded, extruded or thermoformed parts, point 8.1.5
- ☐ spot welding, point 8.1.6
- ☐ seam welding and sewing, point 8.1.7
- ☐ welding of coated cardboard or fabrics, point 8.1.8
- ☐ ultrasonic forming, point 8.1.2
- ☐ riveting, point 8.2.1
- ☐ flanging, point 8.2.2
- ☐ tamping, point 8.2.3
- ☐ ultrasonic embedding of metal parts, point 8.3
- ☐ ultrasonic separating seam welding, point 8.4
- ☐ ultrasonic joining of non-woven textile fabrics (fabrics with mouldings), point 8.5

3. Construction of ultrasonic welding equipment

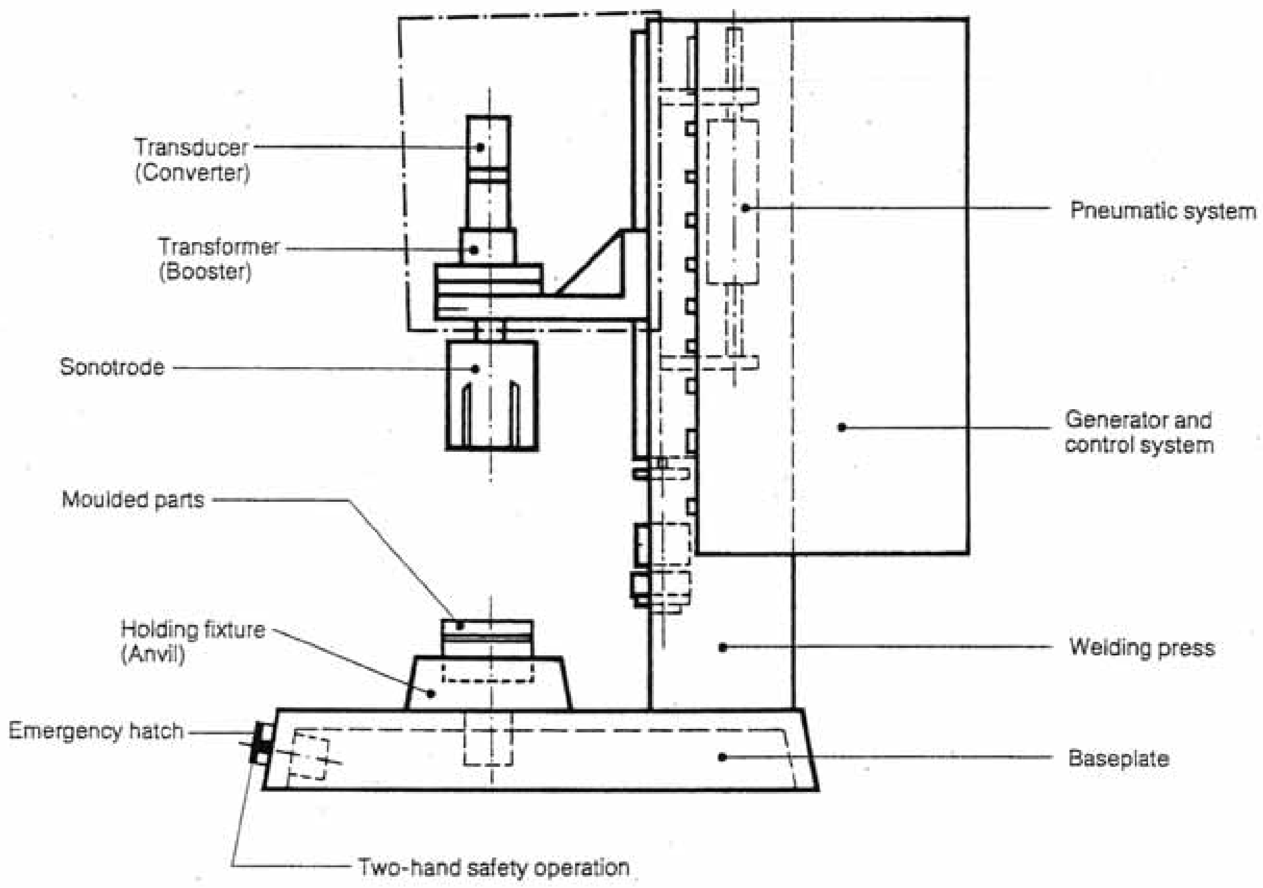


Figure 5: Diagram of construction of an ultrasonic welding apparatus

Ultrasonic welding equipment consists basically of the welding press, the generator, the transducer (converter) with the transformer (booster) and the welding tool (fig. 5). The welding tool consists of a sonotrode and a holding fixture (anvil). The force required for the welding process is produced by the welding press.

3.1 Types of equipment

3.1.1 Manually operated equipment

Manually operated equipment is known as hand welding apparatus or welding guns.

In practice hand welding apparatus tends to be used with generator power outputs between 100 and about 1000 watts. Higher outputs are also possible in exceptional cases. Hand-lever presses are only used for simple jobs.

The hand welding apparatus consists of:

- ☐ generator
- ☐ mechanical resonance unit of the ultrasonic system (transducer in housing with handle and connecting cable).

3.1.2 Pneumatically operated equipment (standard equipment)

In practice pneumatically driven, and in some special cases hydraulically of magnetically driven, welding presses are primarily used. Figure 5 shows a pneumatically operated welding press. In this equipment the generator is incorporated in the top part of the machine or positioned separately. This ultrasonic welding equipment is preferred in cases where a compact welding arrangement is desired.

With the standard ultrasonic welding apparatus the following features are important:

- ☐ compressed air connection (generally 6 bar)
- ☐ contact force (up to about 4000 N at 6 bar)
- ☐ adjustable power stroke
- ☐ adjustable ultrasound switch-on time (triggering)
- ☐ adjustable lowering and impact speed
- ☐ mechanical setting of level of mechanical resonance unit
- ☐ free space between sonotrode and table, as well as between sonotrode and machine column or stand
- ☐ precise guidance of the mechanical resonance unit
- ☐ parallellety of sonotrode and holding fixture.

3.1.3 Special machines and installations

Individual technical solutions to problems are increasingly required and this necessitates the use of special machines or installations. This applies, for instance, to tasks for which the use of an ultrasonic welding unit is not sufficient or to moulded parts with which it is necessary to work on several welding levels and/or different welding positions.

The welding times in ultrasonic installations are very short. As the installations are mainly used for mass-produced articles, it is appropriate to use semi-automatic or fully automatic machines. An extension to the standard installations which is often made is the provision of a round control desk (rotary table) or a linear feed unit.

3.2 Description of the individual components and their method of operation

3.2.1 Generator

The generator converts energy from the mains supply into a frequency required for the mechanical resonance unit. The preferred frequency range is 20 kHz. There are also installations with a frequency up to 50 kHz.

The generator power output required depends upon the particular task. It is customary to operate with a power output in the range 100 to 4000 watts per welding unit.

The no-load power of the generator is made up of the residual losses of the electrical system and the losses of the mechanical resonance unit. Every attempt should be made to keep the no-load power as low as possible. It should always be set at the minimum. The limits given by the manufacturers should be observed!

Power under load is understood to mean the power expressed in watts that the generator provides to the mechanical resonance unit under load at fairly constant amplitude up to the rated load of the generator. The period for which it is switched on and the building-up under load should be taken into account (see operating instructions).

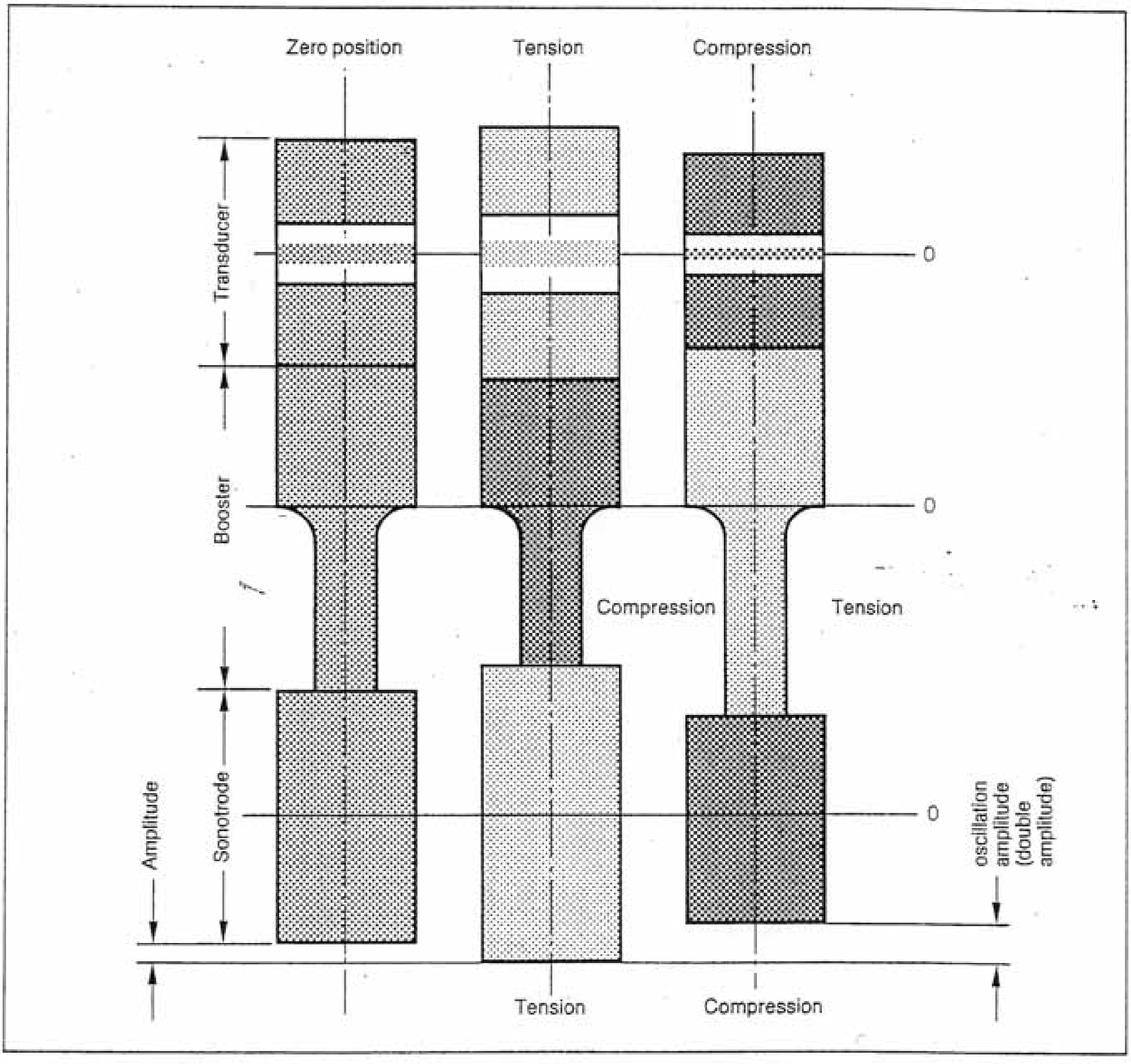


Figure 6: Vibrational mechanism of the mechanical resonance unit of the ultrasonic system

3.2.2 Mechanical resonance unit of the ultrasonic system

It usually consists of the transducer, the booster and the sonotrode. Figure 6 shows the vibrational response of the mechanical resonance unit. On the left of figure 6 the mechanical resonance unit is in a position of rest, in the middle the sonotrode is vibrating in the extensional phase and on the right in the compression phase.

The amplitude is half the total oscillation amplitude. It is measured on the front surface with a dial gauge or an electrical linear measuring instrument; while the total excursion is measured with a microscope.

The oscillation amplitude the total path (peak to peak) covered by the front surface of the sonotrode during vibration.

3.2.2.1 Booster

The booster transmits the mechanical vibratory energy to the sonotrode and transforms the vibration amplitude delivered by the transducer to the value required at the sonotrode.

A mechanical analogy to the task performed by the booster is the gearbox in a car (figure 7).

3.2.2.2 Sonotrode

The welding, riveting or embedding tool known as the sonotrode performs the following operations:

- ☐ it transmits the vibratory energy
- ☐ it transmits the contact force
- ☐ it transforms the amplitude
- ☐ it carries out the forming operation.

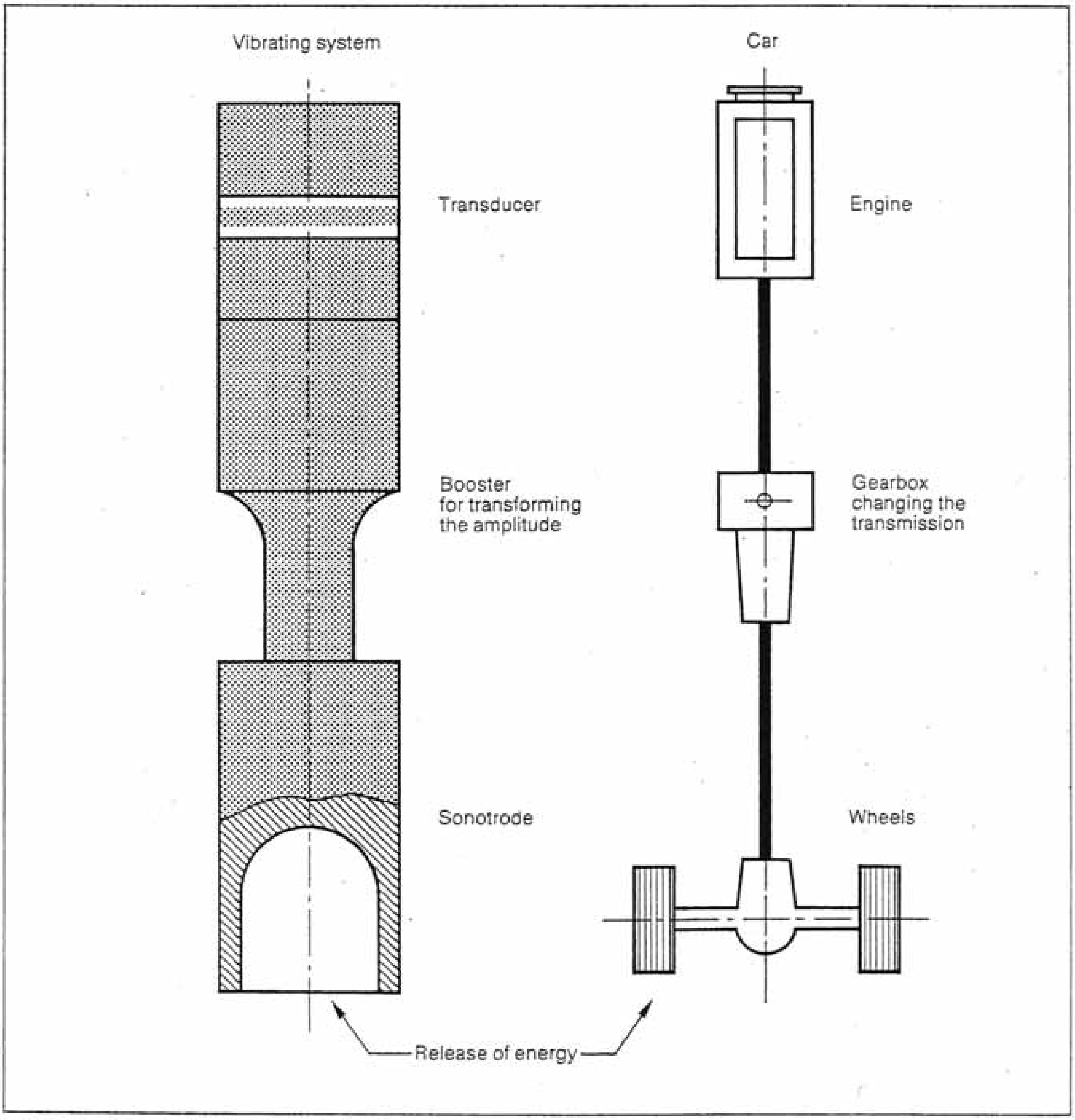


Figure 7: Mechanical analogy booster/gearbox

The sonotrode is particularly important, as good results can only be ensured if it is properly designed for a given moulding. Incorrectly manufactured sonotrodes (wrong frequency, unfavourable transformation and impedance) can result in the destruction of the mechanical resonance unit or in considerable damage to the generator. The manufacture of simple sonotrodes (up to a diameter of about 60 mm) is described under point 9.

3.2.3 Holding fixture (anvil)

The holding fixture is used to position the lower part of the moulding. It can also be used as a guide for the upper part of the moulding (fig. 11). It acts as an end support for the sonotrode. Its work surface is geometrically adapted to the mouldings.

The following materials are preferred:

- ☐ steel
- ☐ aluminium
- ☐ brass
- ☐ cast resins (preferably filled).

In order to protect sensitive moulding surfaces the holding fixture can be fitted with elastic materials (e.g. PTFE, cork, rubber, leather or Elast).

3.3 Facility for setting the welding parameters on the welding apparatus

The control part of the apparatus makes it possible to set all necessary welding parameters.

3.3.1 Welding and holding time

The experience of the users and manufacturers has shown that the welding time should be as short as possible in order to achieve the required welding quality (possibly less than 1.5 sec). If the welding period is longer there is a risk that the moulding will be damaged and where necessary a more powerful ultrasonic welding apparatus must be used. Following the action of the ultrasound there is a short holding or cooling period. The holding period is generally shorter than the welding period.

3.3.2 Point at which the ultrasound is switched on

In practice the ultrasonic energy is switched on before, during or after the placing of the sonotrode on the moulding according to the particular task involved. The switching on can either be time-controlled or pressure-controlled.

3.3.3 Contact force

The contact force is to be coordinated with the amplitude, the output of the installation and the geometrical shape of the joining surface.

3.3.4 Setting the stroke and its speed

The working stroke can be set steplessly and has to be adapted to the particular task involved. The same applies to the speed of the stroke.

3.3.5 Path-dependent control system

In the control system described under 3.1.1 the energy is switched off after the welding time has finished. It is also possible to limit the weld time by means of path-dependent switching off. The switching off can be set and takes place after the pre-selected final position of the sonotrode has been reached.

4. Procedures for optimising the welding parameters

It is recommended that the following sequence should be adopted:

- ☐ determining the amplitude (point 4.1)
- ☐ matching the contact force to the amplitude and generator power output (point 4.2)
- ☐ setting the point for switching on the ultrasound (cushioned or freely vibrating placing of the sonotrode) (point 4.3)
- ☐ setting the impact velocity of the sonotrode (point 4.4)
- ☐ setting the welding and holding time (point 4.5 and 4.6).

4.1 Determining the amplitude

The amplitude is to be coordinated with the material, the construction of the moulding and the geometrical shape of the joining surface (see table 3, page 34).

Mouldings made of semi-crystalline plastics generally require higher amplitudes than mouldings made of amorphous plastics.

The reference values are as follows:

- ☐ amorphous plastics 10 - 30 µm,
- ☐ semi-crystalline plastics 25 - 50 µm.

Establishing an amplitude which is suited to the material and the moulding usually can only be done by experiment. It can best be determined by using boosters with different transformation ratios. For the first experiments it is best to begin with the smallest transformation ratio.

4.2 Matching the contact force to the amplitude and the generator power output

The amplitude and the contact force affecting the joining zone are closely linked with each other. The contact force should therefore be very carefully coordinated with the amplitude, the generator output power and the particular application.

The following can be taken as rough reference values:

low amplitude – high pressure
high amplitude – low pressure

When the welding parameters are being optimised the contact force, starting from the smallest value, is increased until a reliable quality of welding seam has been obtained. The displayed generator power output should be relatively constant after optimisation.

4.3 Setting the point for switching on the ultrasound (triggering)

The triggering effects the time-controlled or pressure-controlled switching on of the ultrasonic energy. The ultrasonic energy can be switched on before, during or after the placing of the sonotrode on the moulding. When the switching on is time-controlled there is a choice of all three possibilities. When the switching on is path-controlled the sonotrode must be vibrating during impact. When the switching on is pressure-controlled there is a possible choice ranging from impact with slight force up to full contact force.

In ultrasonic plastics welding it generally helps if the generator is switched on after the pre-selected contact force has been reached.

In riveting and flange-welding the sonotrode should be vibrating when placed on the moulding, so as to plasticise the synthetic material as quickly as possible.

In the embedding of metal parts the ultrasonic energy has to be switched on before contact is made between the sonotrode and the moulded part, so as to avoid embedding in the insufficiently plasticised drilled hole or cold embedding.

4.4 Setting the impact velocity of the sonotrode

The impact velocity has to be established empirically. It is in the range of about 0.5 mm/sec. to 50 mm/sec. and has a decisive influence on the welding quality.

For riveting, flange-welding, tamping and embedding a slower impact velocity is used.

4.5 Setting the welding time

The welding time depends upon:

- ☐ the generator power output
- ☐ the material
- ☐ the size of the joining surface
- ☐ the sinking depth
- ☐ the ultrasound switch-on point
- ☐ the amplitude
- ☐ the contact force.

It is generally established by experiment. In order to avoid damaging the material of the joining parts the welding time should be kept as short as possible (if possible between 0.2 and 1.5 sec.), and where necessary more powerful ultrasonic welding equipment must be used. In some cases it can be useful to switch off the welding time by means of a path-controlled control system.

4.6 Setting the holding time

The holding time should be tailored to the particular application. It should be kept as short as possible for economic reasons. The exact setting has to be established by experiment. The holding period is generally shorter than the welding period.

5. Raw materials-related influences on the welding response of thermoplastics

As well as the shape of the moulding, the information about the material provided by the manufacturers of the raw materials can also be referred to for a first general assessment of the ultrasonic welding response of thermoplastics. Of this data the following items permit approximate conclusions to be drawn about the welding response.

5.1 Density

This shows in comparison with the basic types whether there are large quantities of additives, e.g. glass fibres (GF), glass globes (GG), asbestos, talcum, etc., which affect the welding response. In most cases the density is increased by these additives.

5.2 Shear modulus G′ and mechanical loss factor tan δ according to the temperature

Favourable welding properties can be expected from a high G′ or E shear modulus which is constant up to the glass transition temperature. At the same time the mechanical loss factor tan δ (attenuation) should be low up to the glass transition temperature and as constant as possible. Hard amorphous plastics have these favourable properties at room temperature (fig. 8). The soundwaves are conveyed to the joining surface without much loss and converted into heat. Most reinforced materials increase the stiffness, as a result of which the shear modulus is also raised.

The shear modulus is also affected in the case of unfilled thermoplastics by the moisture content, the level of crystallinity and the crystal orientation and self-contained stress. These influences are also operative in the case of reinforced thermoplastics.

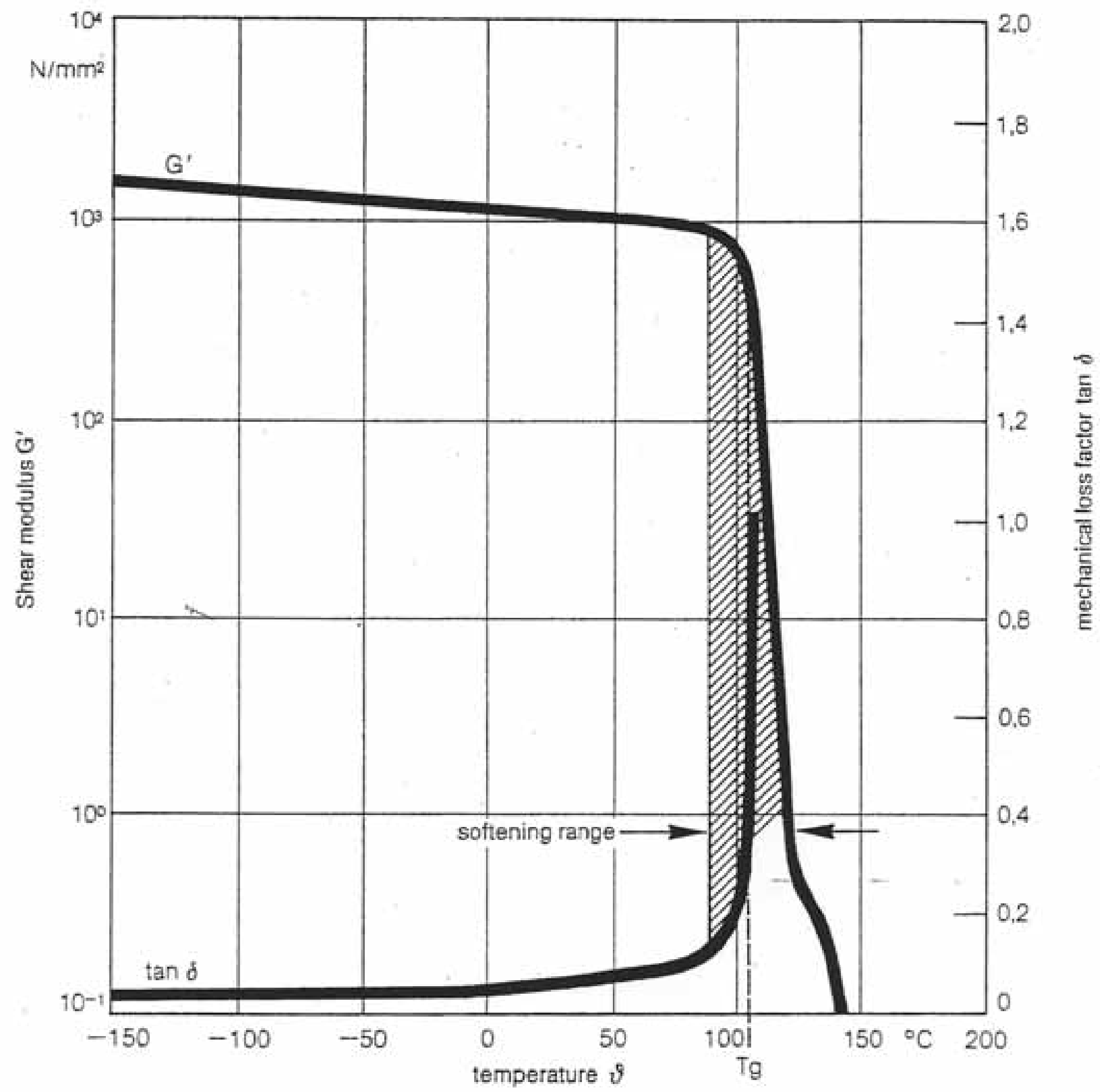


Fig. 8: Temperature behaviour of the shear modulus G′ and the mechanical loss factor tan δ of an amorphous thermoplastic material (SB)

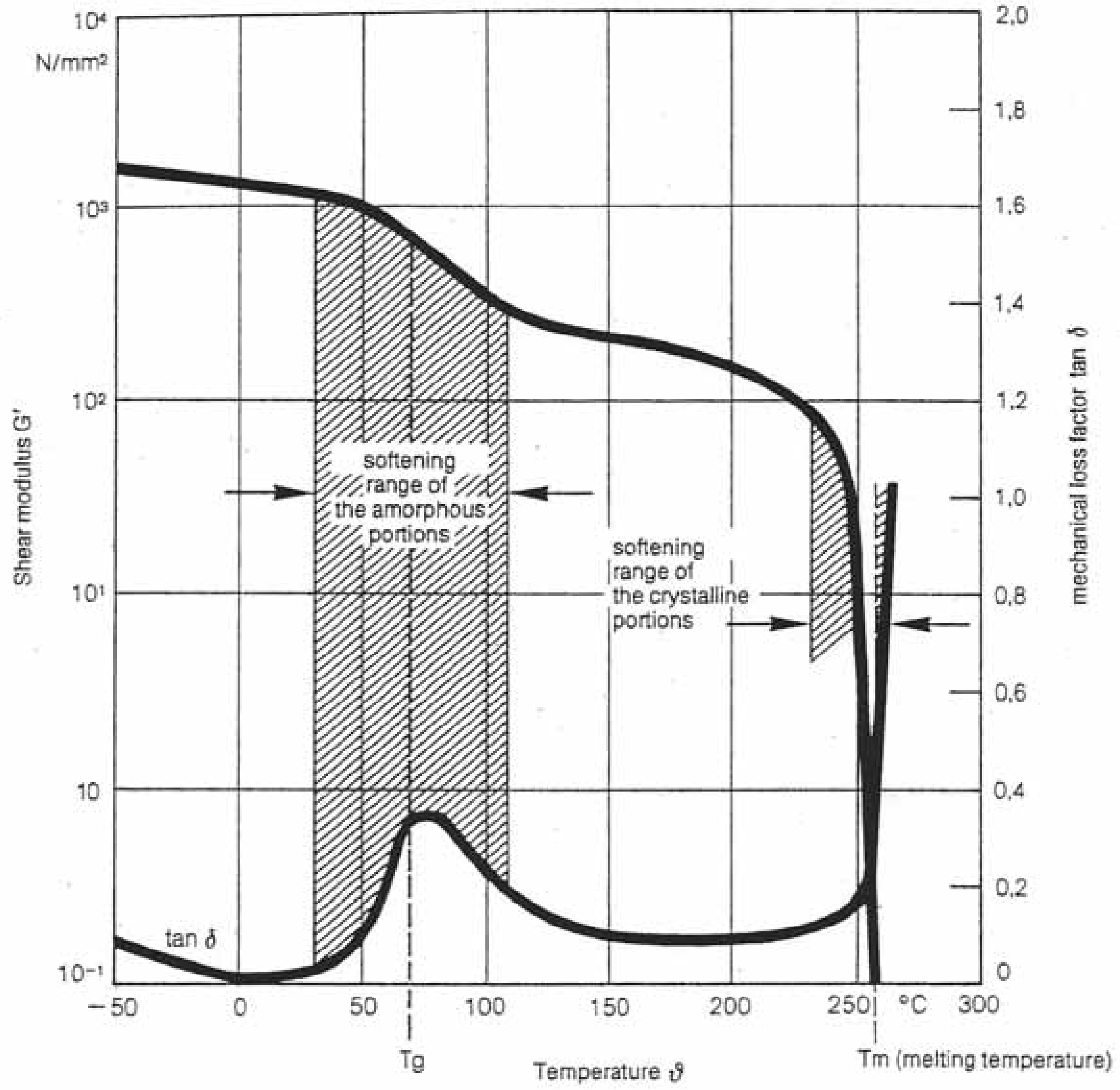


Figure 9: Temperature behaviour of the shear modulus G' and of the mechanical loss factor tan δ of a semi-crystalline thermoplastic material (Polybutylenterphthalat PBTP)

A marked fall in the shear modulus curve up to the glass transition temperature (T_g) or up to the melting zone (T_M) means an increase in the mechanical loss factor and causes a marked attenuation of the sound waves on the way to the joining surface (fig. 9). In general the energy losses are greater in the case of semi-crystalline plastics than in the case of hard amorphous plastics. Mouldings of the same shape usually require a higher generator power output or longer welding period and a higher amplitude in the case of semicrystalline plastics as compared with those made of amorphous plastics. In general it is desirable to have a shorter welding period.

5.3 Melting heat or heat content and specific calorific capacity C_p

The higher the value is in particular at the glass transition temperature or in the melting range, the greater the amount of energy which is required for plasticising the material in the joining zone. This means a longer welding period or where necessary a more powerful ultrasonic welding installation, the latter being preferable.

5.4 Melting range or thermoplastic range

The heating of the joining zone beyond the melting range must be guaranteed by the choice of appropriate welding parameters (point 4).

5.5 Sound velocity

The sound velocity in the synthetic material is temperature-controlled and is important where the moulding acts as a sound conductor, e.g. in far-field welding.

5.6 Melt viscosity

The viscosity of a plastic melt (expressed, for instance, by the MFI Melting Index) influences the welding response.

High-molecule, viscous plastics, characterised by a low MFI, generally require more energy to be melted. This means a longer welding period or that a higher power output of the ultrasonic welding apparatus is necessary.

Plastics with a low melt viscosity, characterised by a high MFI, melt more quickly. Molten material can suddenly leave the joining zone in such cases. To avoid this the welding pressure, the welding period, the amplitude, the triggering and the design of the joining zone should be coordinated with particular care.

Most reinforced and filling materials increase the melt viscosity, i.e. the molten material is more viscous. Small quantities of some fillers, e.g. mica and talcum, reduce the melt viscosity and the molten material is more mobile and flows more quickly.

5.7 Reinforced materials, filling materials and other additives

Reinforced materials:
Glass fibres, glass globes, carbon fibres, talcum, asbestos, etc.

Filling materials:
Wood flour, chalk and other mineral and organic filling materials.

Other additives:
Stabilisers, lubricants, dyes, softeners, flame-retarding additives, anti-static coatings, etc.

The nature and quantity of these additives can affect the welding response and the welding result. The construction of the mouldings and the welding conditions should be adjusted accordingly.

6. Influence of the conditions in which the mouldings are manufactured on the welding response

It is mainly injection-moulded parts which are welded ultrasonically, and in some special cases moulded parts which are manufactured by blow moulding, thermoforming or extrusion.

The mouldings must be manufactured under conditions suited to the particular type. The reason for defective welding is often to be found in unsuitable manufacturing conditions.

6.1 Injection-moulded parts

6.1.1 The effects of moisture

As a result of too high a moisture content in certain thermoplastics damage is caused in injection moulding and in welding by streaks, bubbles or porous structures. This reduces the usefulness, the visual appearance and the quality of the welded joint. Thermoplastics which are too damp should therefore be dried before welding.

With a number of plastics, e.g. types of polyamide, the desirable maximum viscosity should first be obtained by conditioning (moisture absorption). As well as this desired increase in the moisture content, a number of other thermoplastic mouldings also absorb undesired moisture from the atmosphere.

As ultrasonic welding of damp mouldings leads in both cases to bad results – porous welding seams, longer welding times – conditioning should be carried out only after the ultrasonic welding. Moisture-sensitive mouldings must be protected right up to welding (e.g. in PE bags). For the ultrasonic riveting and flanging of polyamide parts a slight moisture content can be an advantage. The advice on drying and processing contained in the information sheets of the raw materials producers should be followed.

6.1.2 Influence of the processing conditions

A tool which is designed badly or which is not suited to the material, as well as wrong processing conditions, can have an adverse effect on the production of moulded parts by injection moulding and lead to poor welding results.

These can include:

- ☐ fluctuations in size (contraction, after-contraction, warpage)
- ☐ fluctuations in weight (level of filling)
- ☐ surface defects (sunk spots, imperfect outline of the joining surface)
- ☐ lack of uniformity (shrinkage cavities, flow seams, stresses)
- ☐ processing defects (decomposition, separation)
- ☐ excessive internal stresses (particularly in the case of amorphous plastics).

6.1.3 Minimum duration of storage

Injection-moulded parts made of partially crystalline thermoplastics should not be welded immediately after being taken from the injection moulding machine, because after-contraction in welded parts can produce undesired stresses (warpage) or even cause them to be destroyed. A minimum duration of storage between injection moulding and ultrasonic welding of 24 hours is therefore necessary. Injection-moulded parts made of amorphous thermoplastics do not require this minimum duration of storage.

6.1.4 Regenerated materials

What has been stated above applies to the use of original material. The addition of considerable quantities of regenerated materials can have an adverse effect on the welding properties of mouldings.

6.1.5 Mould release agents and impurities

Deposits of mould release agents or impurities on the joining surface should be avoided. If it is not possible to dispense with mould release agents, it should be borne in mind that the mouldings display differing quantities of the mould release agent on the joining surface and can adversely affect the welding properties. Where necessary, the mouldings should be cleaned.

6.2 Extruded semi-finished products and blow moulded parts

The same influencing factors as listed under 6.1.1 to 6.1.5 apply to blow moulded, thermoformed and extruded mouldings.

7. Design of mouldings

The injection moulding method presents the simplest way of producing satisfactorily welded mouldings. A number of important factors should be observed in the construction of the mouldings, the design of the sonotrode and the holding fixture, and also during welding. Examples are described in the following sections.

The different welding responses of thermoplastics should be taken into account in the choice of material. The mouldings which are to be joined should be constructed in such a way that the plasticisation necessary for welding is present in a reproducible way in the joining surface.

The necessary preconditions for obtaining high-quality weldings should already be created in the planning phase. Depending upon what is required of the welded joint, the demands which the construction should take into account include the following:

- ☐ load capacity of the welding seam
- ☐ leaktightness with regard to liquids and gases
- ☐ visually attractive appearance
- ☐ the avoiding of expelled molten material and synthetic particles inside the mouldings.

As well as by the welding parameters (point 4), the quality of the welded joint that can be obtained is affected by the following factors:

- ☐ the nature of the material
- ☐ the construction of the moulding
- ☐ the position and design of the joining surfaces
- ☐ the arrangement of the energy director
- ☐ the positioning and clearance between the upper and lower part
- ☐ the coupling of the sonotrode
- ☐ free sinking path
- ☐ support in the holding fixture.

7.1 Construction of the mouldings

The mouldings should be rigid. Sufficiently thick walls should be provided for. There is a danger of damage with mouldings the walls of which are too thin.

7.1.1 The rounding-off of corners and edges

All corners and edges should be rounded off adequately on the mouldings. Minimum radii of 0.2 to 0.5 mm are suggested. This is particularly important in the case of hard plastics. In ultrasonic welding junctions which are too sharp can result in fractures.

7.1.2 Position of the joining surface and the distance from the sonotrode

The position of the joining surface should be as vertical as possible to the axis of the sonotrode and parallel to the front surface of the sonotrode. The joining surface should also be on one plane. Where this cannot be done, it is recommended that contact should be made with the manufacturers of the ultrasonic equipment or the producers of the raw materials.

The distance between front surface of the sonotrode/joining surface should be small (see also near-field and far-field welding, points 8.1.1 and 8.1.2).

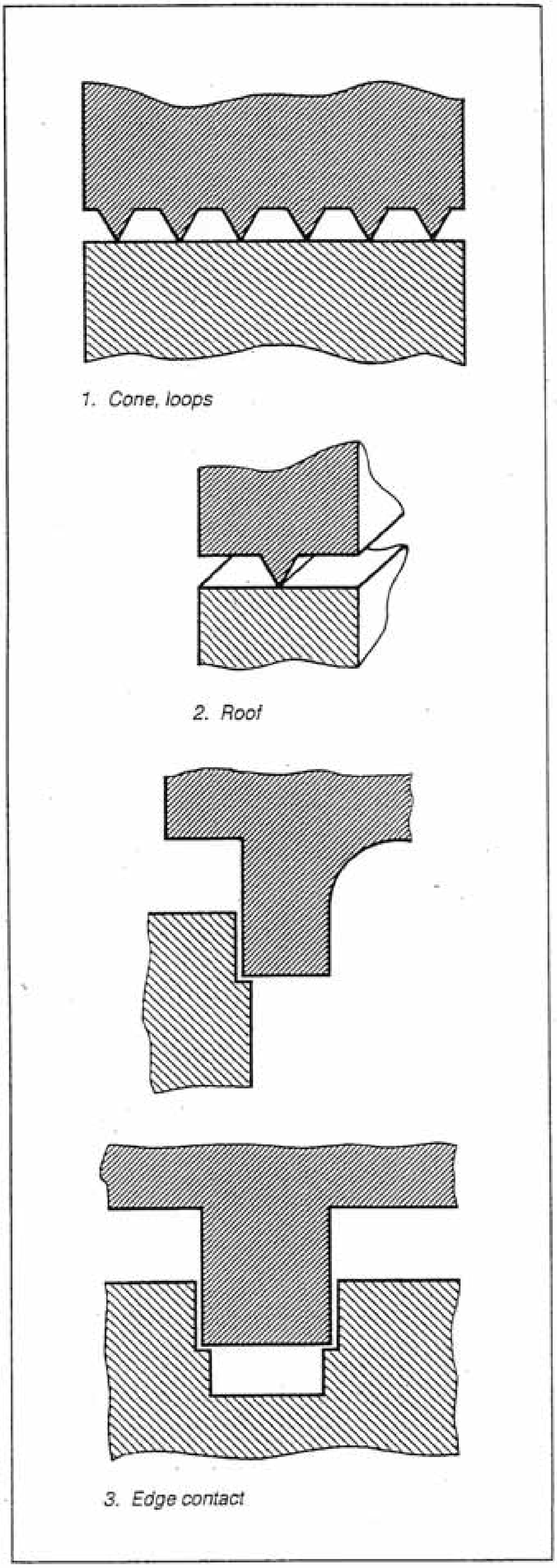


Fig. 10: Basic forms of the energy director

7.1.3 Size and design of the joining surface

The geometry of the joining surface is to be tailored to the requirements in relation to the welding seam. Decisive factors are:

- ☐ the nature of the material
- ☐ the construction of the moulding.

Provision should be made for energy directors (energy concentrators) in order to obtain short welding cycles and to avoid damage. A distinction is made between cone-shaped, loop-shaped and roof-shaped energy directors, as well as the edge contacts which act as energy directors for flattened seams.

7.1.4 Energy director (ED)

The function of the energy director is to initiate rapidly the plasticisation of the joining surface by the concentration of energy. Any shape or size of the ED can be chosen within certain limits. The following basic shapes (fig. 10) can be distinguished according to the nature of the plastic, the construction of the moulding and what is required of the welded joint.

- ☐ Cone or loop-shaped energy director
- ☐ roof-shaped energy director
- ☐ edge contacts for simple and double shear joints.

It does not as a rule make any difference to the welding result on which half of the moulding the EDs are fitted. In special cases (as in different combinations of plastics) the best position should be found out by experiment. In the case of mouldings with varying ridigity the EDs should be placed in the softer moulded part.

7.1.5 Centring of mouldings

The upper and lower part of the moulding should be centred in such a way that they retain their position during welding. The centring height should not be below 1 mm. As a rule, centring should where possible be over the moulding.

The allowance for clearance between the upper and the lower part should be small, at least 0.05 mm, however. This clearance should also be present in the case of sloping and tapering walls up to the final sinking depth. Where a combination of mouldings made of different types of plastics (e.g. reinforced/non-reinforced) is concerned, their different fading rates should be taken into account.

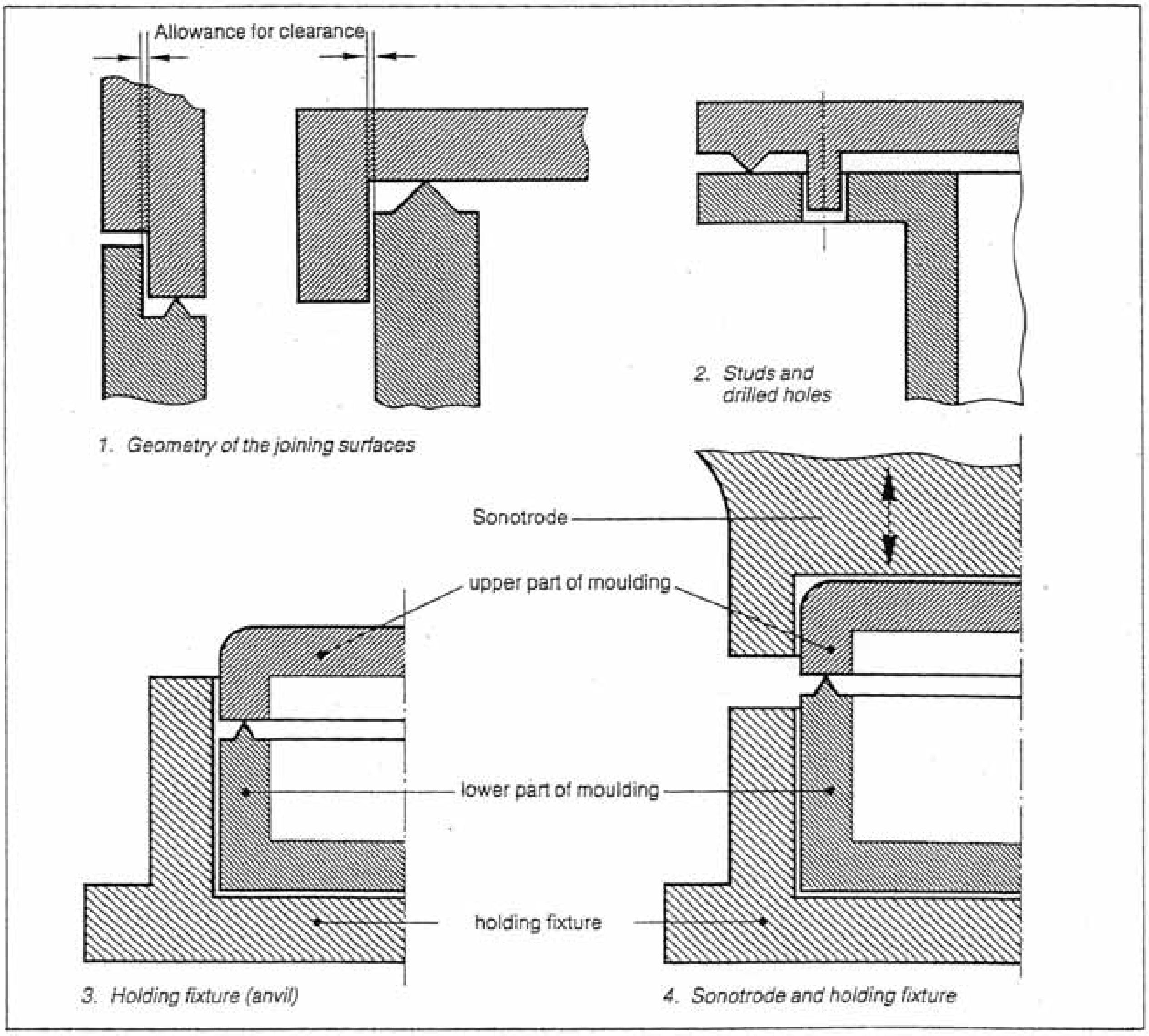


Figure 11: Possible ways of centring mouldings

The following methods of centring (fig. 11) are chosen:

- ☐ by the geometry of the joining surfaces
- ☐ by the stud and the drilled hole
- ☐ by the holding fixture
- ☐ by means of centring by sonotrode and the holding fixture. (This can only be used where there is a particularly high dimensional accuracy of the mouldings. This method of centring is only used in special cases.)

7.1.6 Free sinking path of the upper part

The upper part must be able to sink unhindered in ultrasonic welding. No edges, ribs or bridges must be able to intercept the upper part during the sinking movement.

7.1.7 Resonance of ribs, butts, bolts and other functional elements

Free-standing ribs, butts, bolts and inserted parts can be damaged during ultrasonic transmission or can cause damage to the moulding. It is possible to remedy this by having sufficiently large radii on corners, edges and junctions, short welding times or also by the use of vibration-absorbing bases.

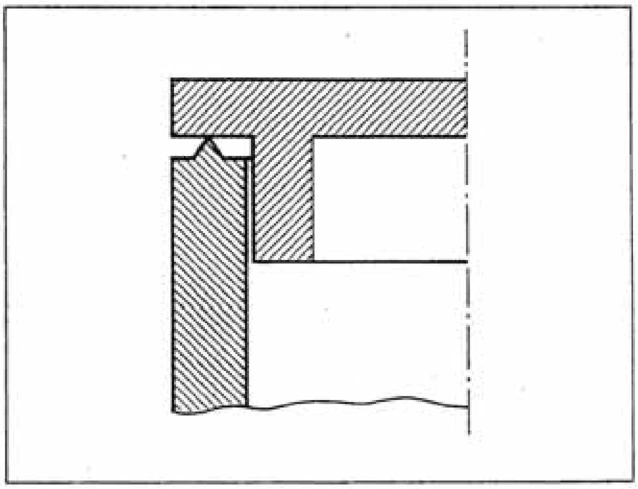


Figure 12: Welding seam covered inwards

7.1.8 Separation of particles during welding

During welding particles can separate from the welding seam or its surroundings and penetrate into the interior of the mouldings. This can be avoided to a large extent by the covering of the welding seam (fig. 12).

7.1.9 Support in the holding fixture

The lower part of the moulding should be supported sufficiently in the holding fixture and centred for the welding operation (see also point 3.2.3). With thin-walled mouldings and particularly with flattened seams it is advisable to support the side walls almost up to the joining zone (fig. 13).

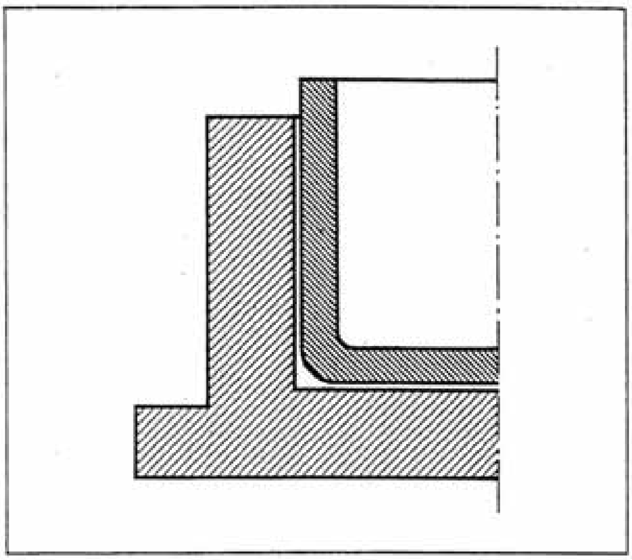


Figure 13: Supporting of the lower part of the moulding in the holding fixture

7.1.10 Coupling surface of the sonotrode

For the coupling of the sonotrode there sould as far as possible be a level surface which is adapted to the moulding and sufficiently large (fig. 14). Where the dimensions of the surface are too small the transmission of the ultrasound is reduced. Damage to the coupling surface is the consequence.

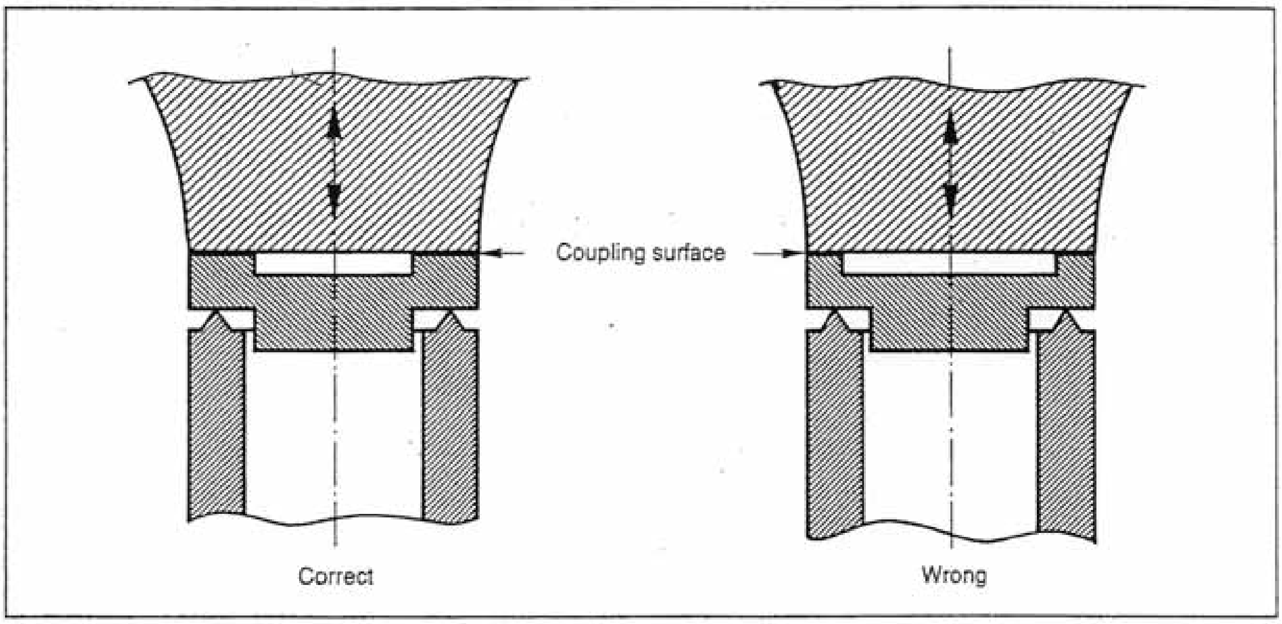


Figure 14: Coupling the sonotrode with the moulding

By touching up or by using carbon paper, to which a sheet of thin white paper is attached, it is possible to show whether the contact between the sonotrode and the surface of the moulding is uniform.

The coupling of the sonotrode to highly polished or structured surfaces can result in markings. The effect of such marks can be reduced by the use of sheeting placed between the sonotrode and the surface, e.g. PE sheeting.

7.2 Geometry of the joining surface

If there is no available experience in choosing the dimensions of the energy director, it is advisable for reasons of easier re-working by injection moulds to begin with low levels of the energy director (ED).

7.2.1 Joining surface design with cone-shaped and loop-shaped energy directors

EDs of this kind can be used for joining moulded parts and flat parts. Figure 15 shows the lower part of a moulding with cone-shaped energy directors. They are not suitable for seal welds.

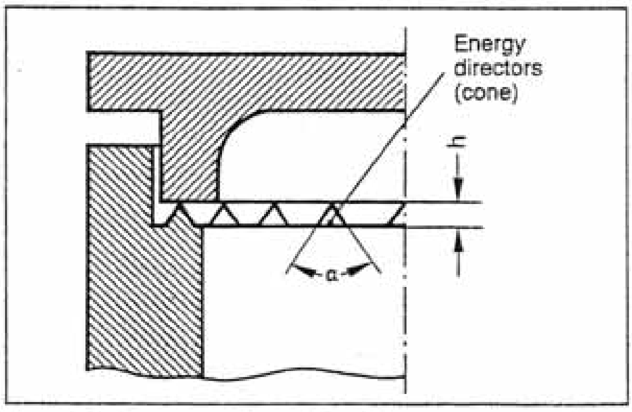


Figure 15: Lower part of moulding with cone-shaped energy directors

Angle α is about 60 to 90°. The height of the ED is between 0.2 and 1 mm. With semi-crystalline plastics the EDs should generally be designed higher than with amorphous plastics.

7.2.2 Joining surface design with roof-shaped energy directors

Welding seam patterns with roof-shaped EDs can be used with almost all moulding dimensions. The ED should

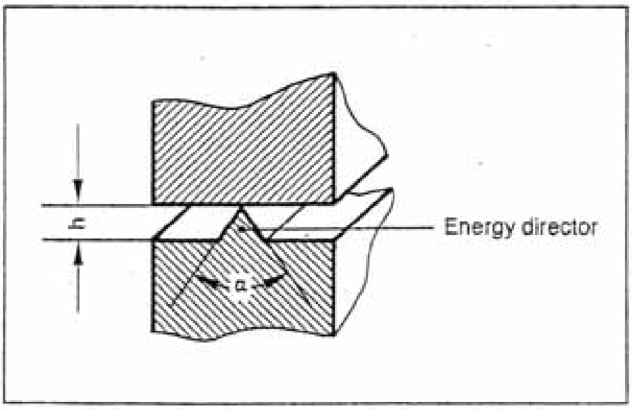


Figure 16: Roof-shaped energy director

have an angle of between 60 and 90°. The height h can be between 0.2 and 1 mm, in special cases up to 2 mm, according to what is required of the welded joint (fig. 16).

A symmetrically arranged ED is to be preferred to an asymmetrical one. It should meet the opposite joining surface as near as possible to the centre. In exceptional cases several small EDs can be used instead of one large one. They can be staggered and also arranged at different heights.

We show below in figures 17 to 22 a number of shapes of joining surfaces which have proved their worth. The proportions can be changed within certain limits. Special shapes are likewise possible.

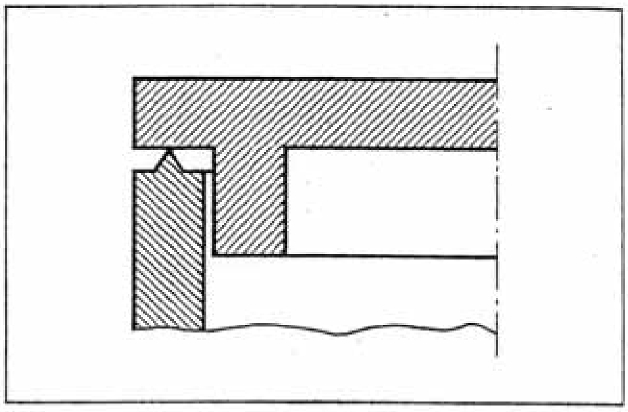


Figure 17: Upper part with inner centring. Welding seam covered inwards, molten material can flow outwards.

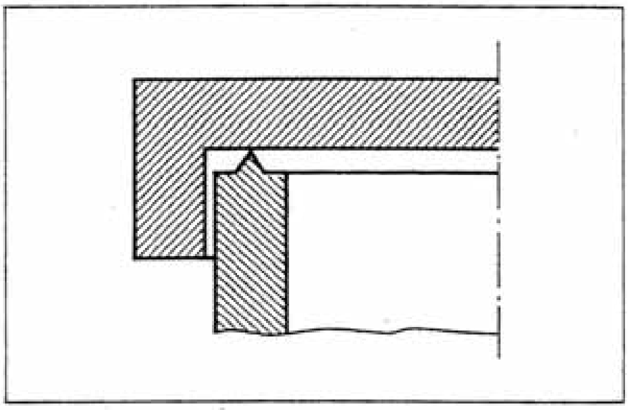


Figure 18: Upper part with outer centring. Welding seam covered outwards; molten material can flow inwards.

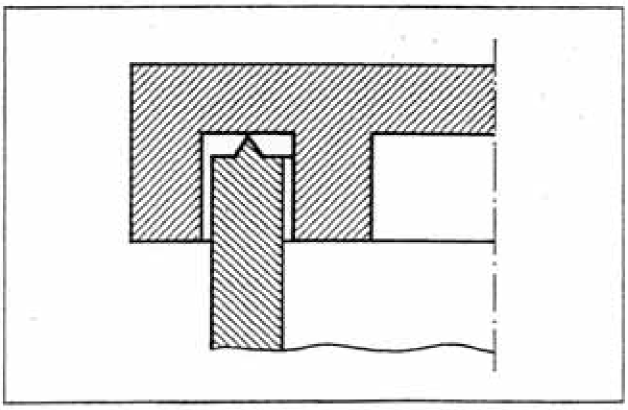


Figure 19: Upper part with double-centring. Because of the requirement of high dimensional stability preferably only used with fairly small moulding dimensions.

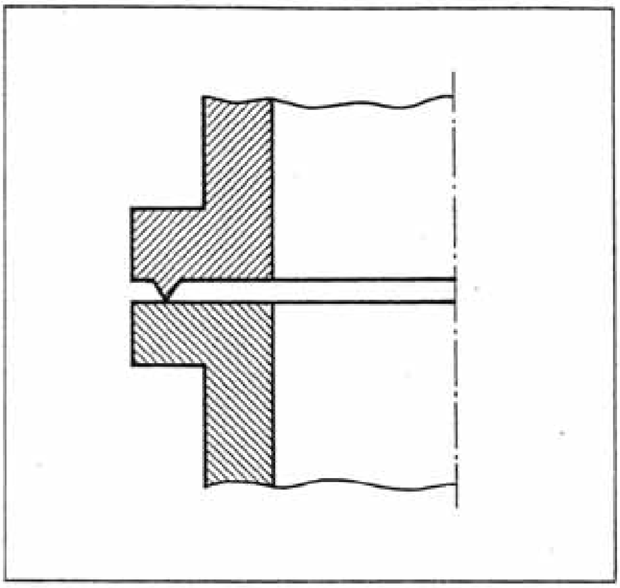


Figure 20: Shape of seam for fairly large mouldings.

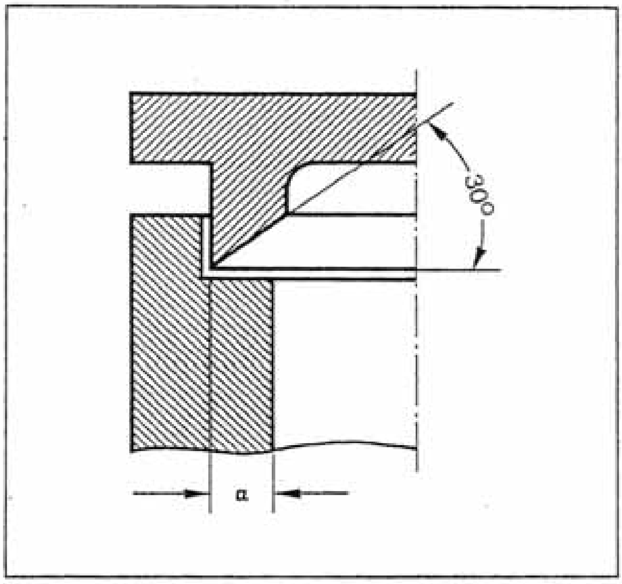


Figure 21: Upper part with inner centring, a > 0.6 mm.

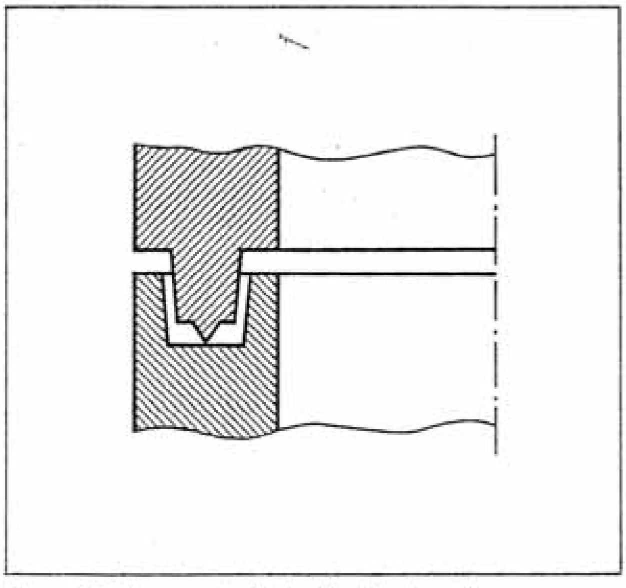


Figure 22: Upper part with double-sided centring.

Larger units can also be welded with the type of seam illustrated in fig. 20. The sonotrode has to be brought down on the flange of the upper part. The flange of the lower part has to be supported by the holding fixture. By centring on the upper or lower part the seam can be covered internally or externally. This type of seam is useful in welding for polyolefine.

Fig. 21 shows an upper part with inner centring and asymmetrical energy director. This type of joint is most suited to ultrasonic welding of hard amorphous and partially crystalline plastics.

Fig. 22 depicts an upper part with double-sided centring in the lower part. The clearance at the side must be maintained until the complete sinking depth has been obtained. On account of the requirement for high dimensional stability this is best used only with fairly small moulding dimensions.

7.2.3 Design of joint surface with shear joints (SJ)

Shear joints (step joints) are preferred for seal welds and when semi-crystalline plastics are used. The mouldings whould have a narrow tolerance and the allowance for clearance should be small. The side walls of the lower parts should be supported up to the level of the weld. Fig. 23 illustrates the principle of a shear joint.

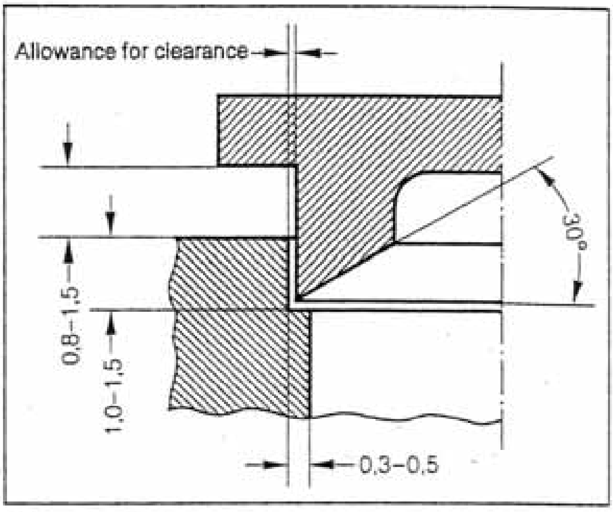


Figure 23: Principle of a shear joint

Figures 24 to 27 show types of design of shear joints which have proved their value.

Figure 25 shows double shear joints with and without ED on the lower part. Because high dimensional stability is required this is best used only with fairly small moulding dimensions.

Double shear joints with and without ED on the lower part can be seen in figure 26. The second shear joint is only effective with increasing sinking movement of the upper part. Because of the required dimensional stability it can only be used with fairly small moulding dimensions.

Stud welding is adopted for joining mouldings which are to be welded firmly, but not close to one another. It can be used with most hard amorphous and semi-crystalline plastics. Approximately the same considerations apply for the dimensioning of the joining surfaces as in the case of shear joints (figure 27). In exceptional cases seal welds are possible as a result of adding elastic seal elements.

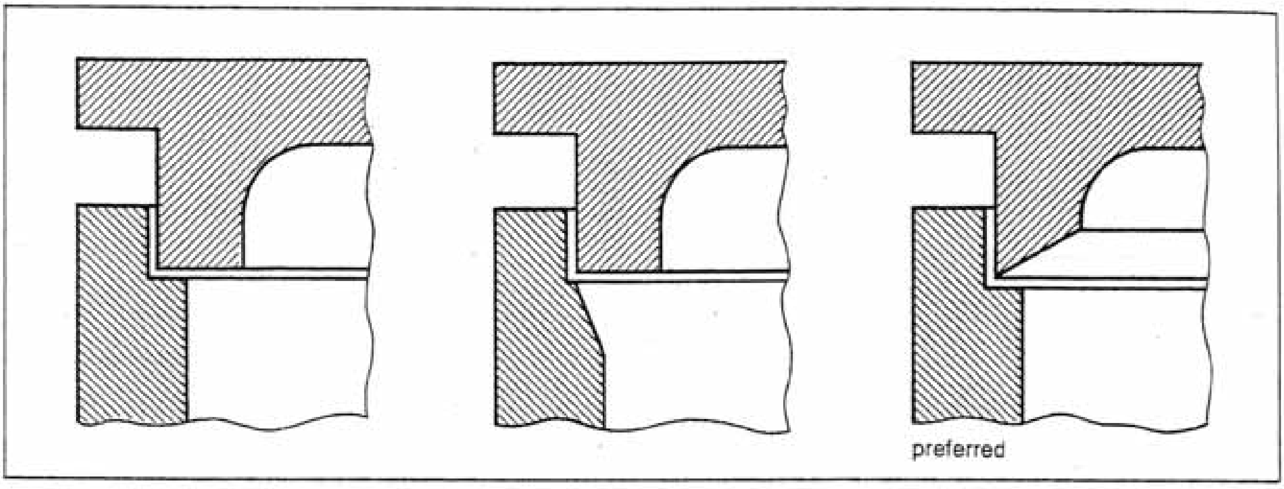


Figure 24: Simple shear joints

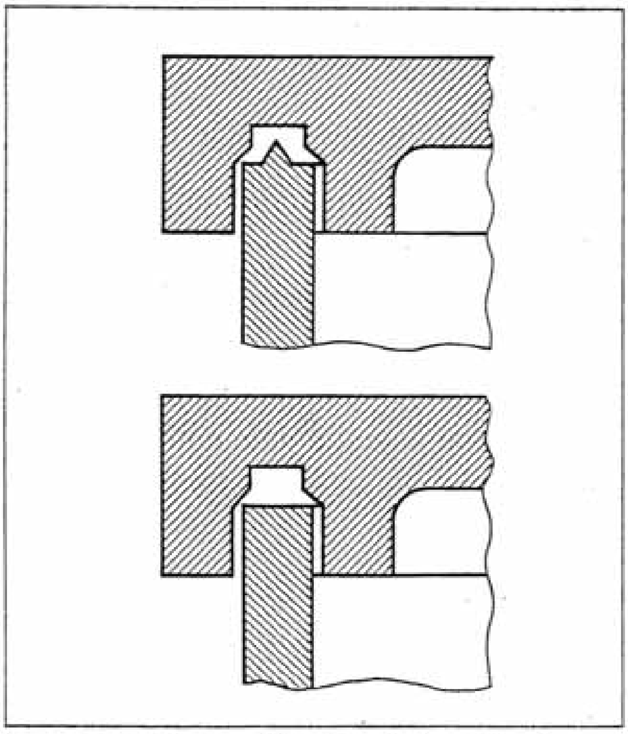


Figure 25: Double shear joint with and without ED on the lower part.

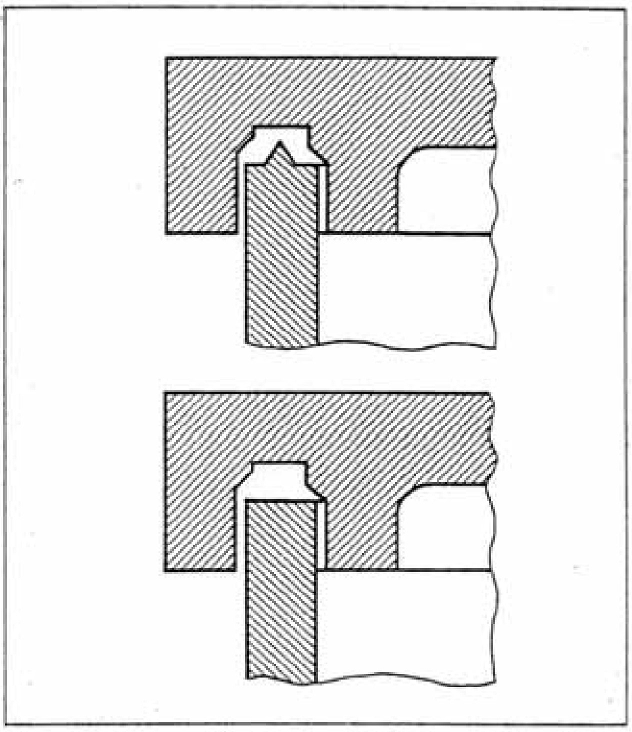


Figure 26: Lowered double shear joint with and without ED on the lower part.

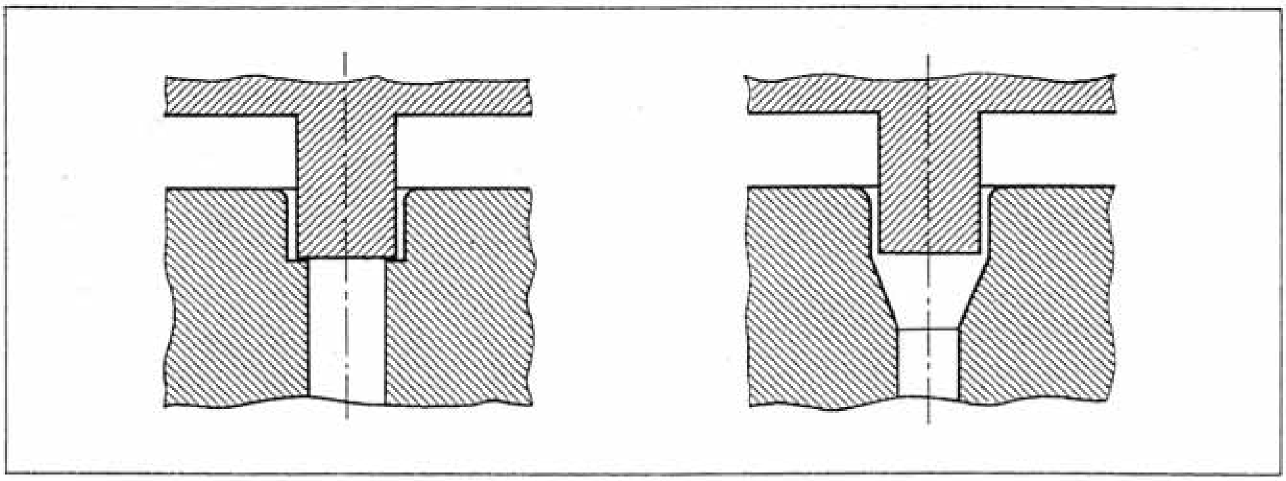


Figure 27: Stud welding

8. How to apply the different processes

8.1 Ultrasonic welding

According to DIN 16960 a distinction is made between near-field (direct) and far-field (indirect) ultrasonic welding.

8.1.1 Near-field welding (direct ultrasonic welding)

The joint surface is near to the front surface of the sonotrode, i.e. the distance of the contact surface of the sonotrode/plastic moulding from the joint surface can be up to about 6 mm (figure 28).

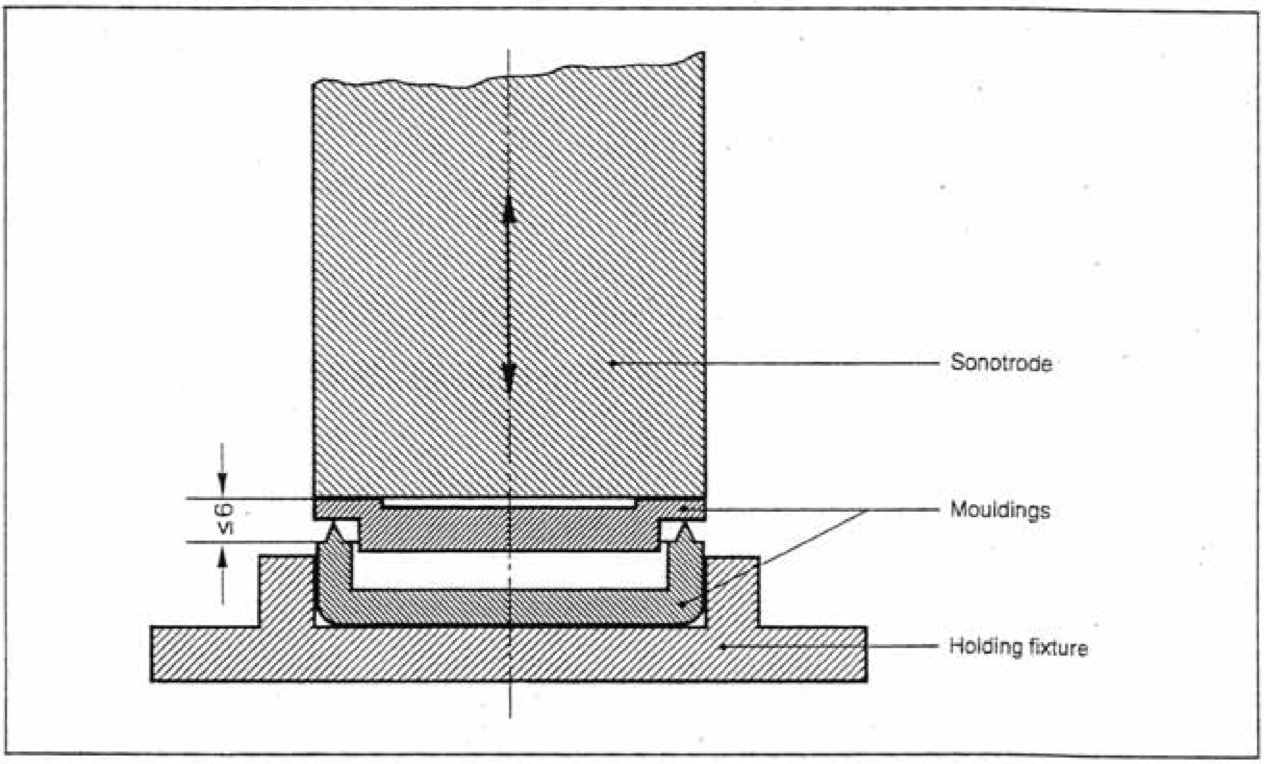


Figure 28: Ultrasonic welding in the near field

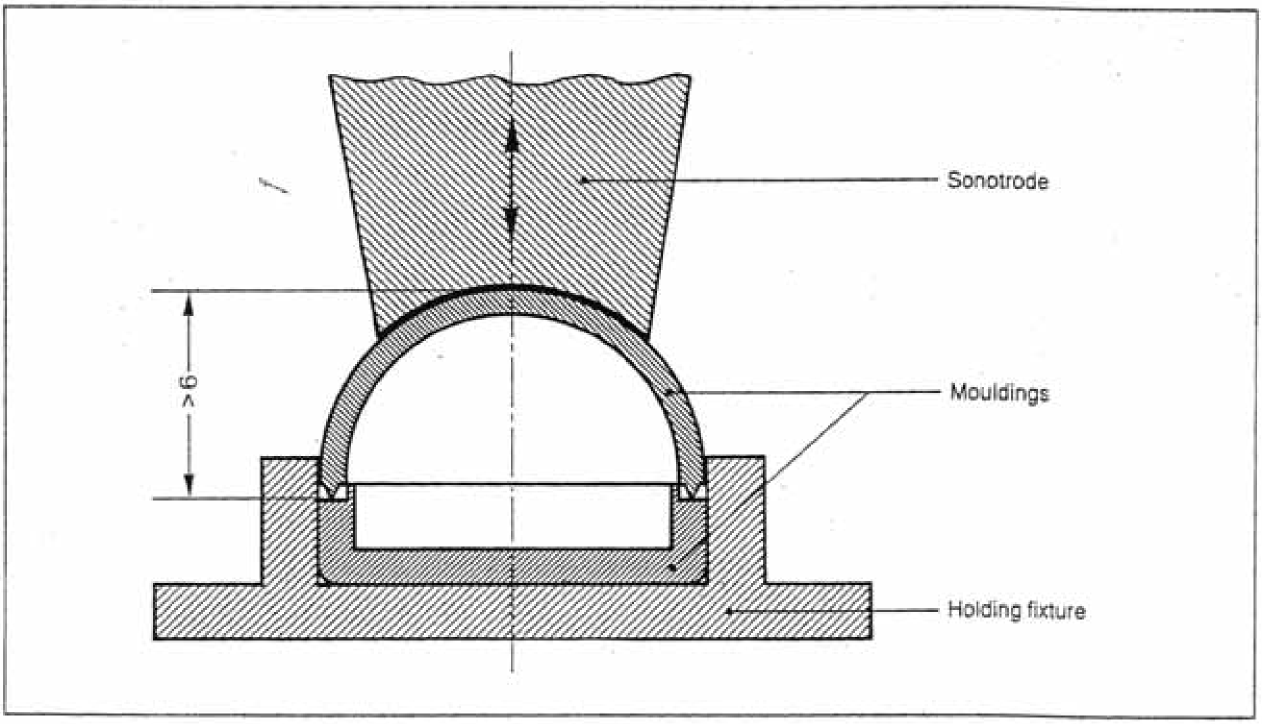


Figure 29: Ultrasonic welding in the far field

8.1.2 Far-field welding (indirect ultrasonic welding)

The distance between the contact surface of the sonotrode/plastic moulding and the joint surface is more than about 6 mm. The ultrasonic energy is transmitted through the upper moulding wall to the joint surface (figure 29). For this reason only sufficiently rigid plastic parts (e.g. PS, ABS, AB, PMMA) can be welded by means of the indirect ultrasonic welding technique. A number of semi-crystalline plastics (e.g. POM, PETP, PBTB, PA) can also be welded in the far field given a favourable geometry of the moulding.

The plastic between the front surface of the sonotrode and the joint surface is scarcely heated.

8.1.3 Welding with an inserted seal

Tight welds can generally be produced with ultrasonic welding. This applies to most joint surface designs, but particularly for shear joints. In exceptional cases seal welds are obtained via an inserted elastic seal (e.g. O rings). Figure 30 shows an example.

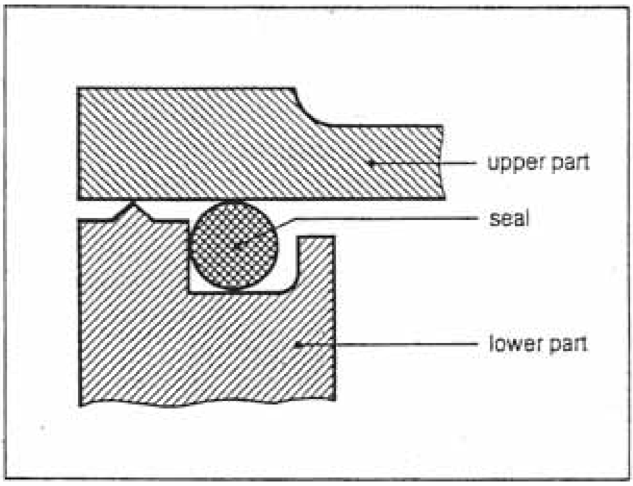


Figure 30: Ultrasonic welding of mouldings with inserted seal.

8.1.4 Welding of mouldings – injection moulded, extruded, blow moulded, thermoformed – with semi-finished products or sheeting

When there are no energy directors available or when they can only be obtained at great expenditure, it is recommended that the spot welding method (figure 31) should be adopted (see point 8.1.6).

In ultrasonic welding of sheeting with injection moulded, extruded, blow moulded or thermoformed mouldings or with sheeting, sonotrodes with grooves (diamond-shaped patterns, edges) of the welding surface should be used.

8.1.5 The welding of mouldings – combination of injection moulded, extruded or thermoformed parts

Injection moulded parts can be welded with blow moulded, extruded or thermoformed mouldings. The energy director is injected on the injection moulded parts. The mouldings should as far as possible consists of the same type of plastic. In figure 32 the lid has been ultrasonically welded with a yoghurt carton.

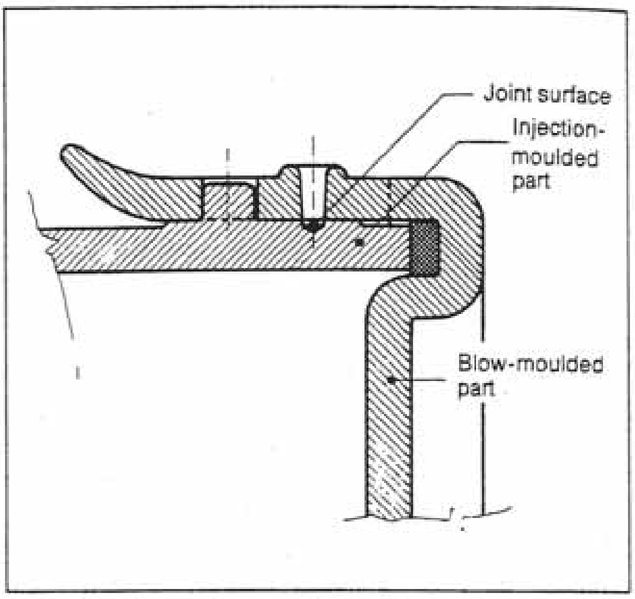


Figure 31: Ultrasonic spot welding of blow moulded and injection moulded parts

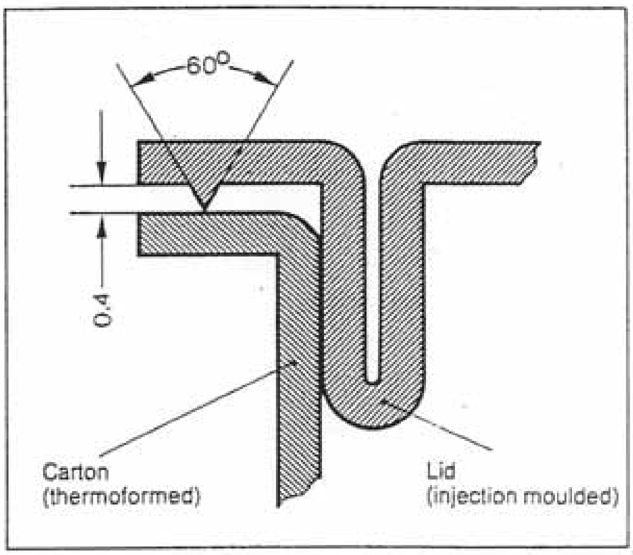


Figure 32: Ultrasonic welding of thermoformed with injection moulded parts.

8.1.6 Spot welding

Ultrasonic spot welding is used predominantly where for instance flat mouldings without weld preparation (ED) have to be welded (e.g. semi-finished products, thermoformed, blow moulded, extruded and large-surface mouldings).

Figure 33 illustrates the principle of spot welding. The tip of the sonotrode penetrates through the upper part into the lower part. Heat is produced on the contract surfaces of the mouldings, as a result of which the material is plasticised and welded. The expelled plastic flows upwards and forms a ring-shaped elevation. The back of the lower part remains largely free of marks. The mouldings can be fixed appropriately by hold-downs or clamping devices. The thickness of the moulding adjacent to the sonotrode should not exceed 8 mm. Spot welding can also be carried out with a moveable ultrasonic hand welding apparatus (welding gun).

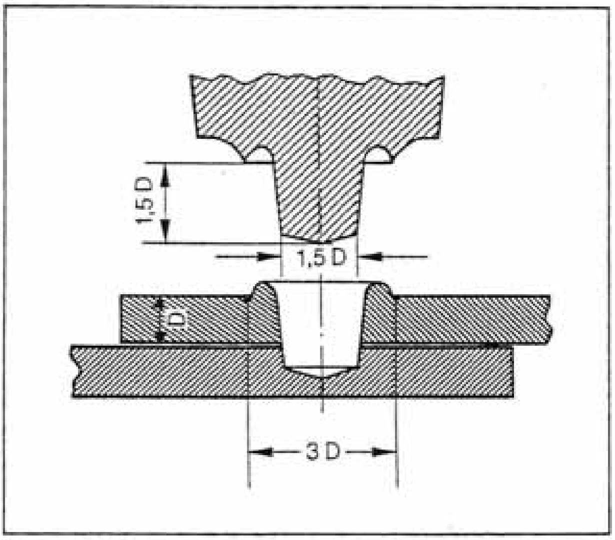


Figure 33: Principle of ultrasonic spot welding

8.1.7 Seam welding and sewing

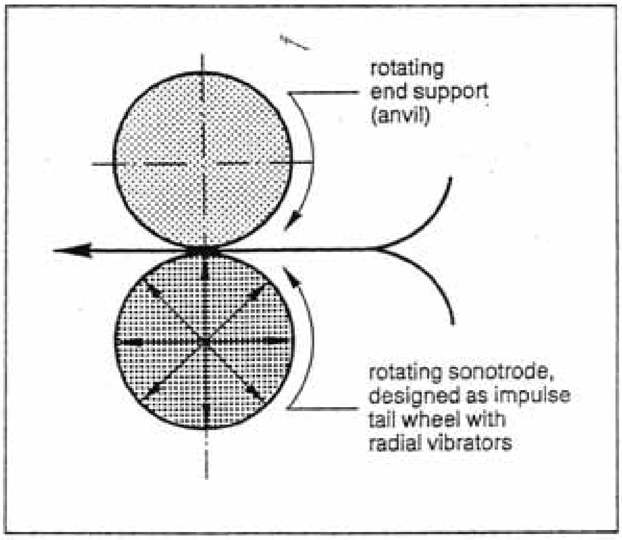


Figure 34: Ultrasonic seam welding, continuously powered by the sonotrode.

The welding of mouldings and semi-finished products (sheeting, fabrics, plates, profiles) is done in the shape of a seam. Figures 34 to 37 show variants of seam welding.

With the aid of special open 'ultrasonic sewing machines' fabrics, knitted fabrics and sheeting are 'sewn, hemmed, pleated, stitched and stamped'. The proportion of natural fibres can be up to 35%.

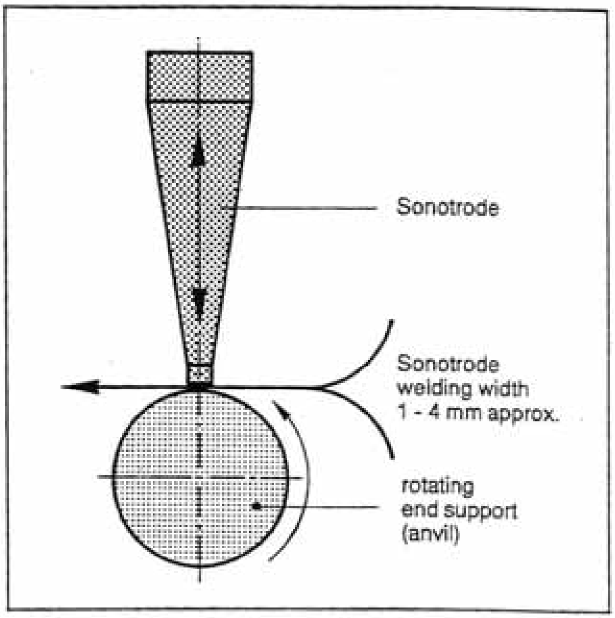


Figure 35: Ultrasonic seam welding, continuously powered by the rotating end support.

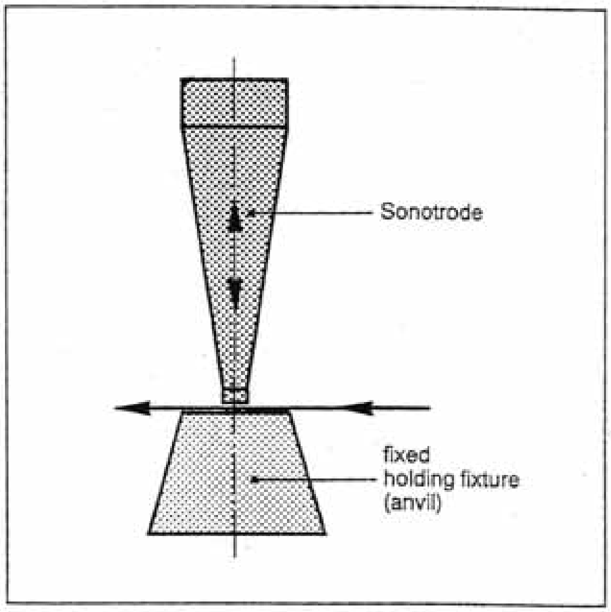


Figure 36: Ultrasonic seam welding, transport of sheeting only by traction of the foil.

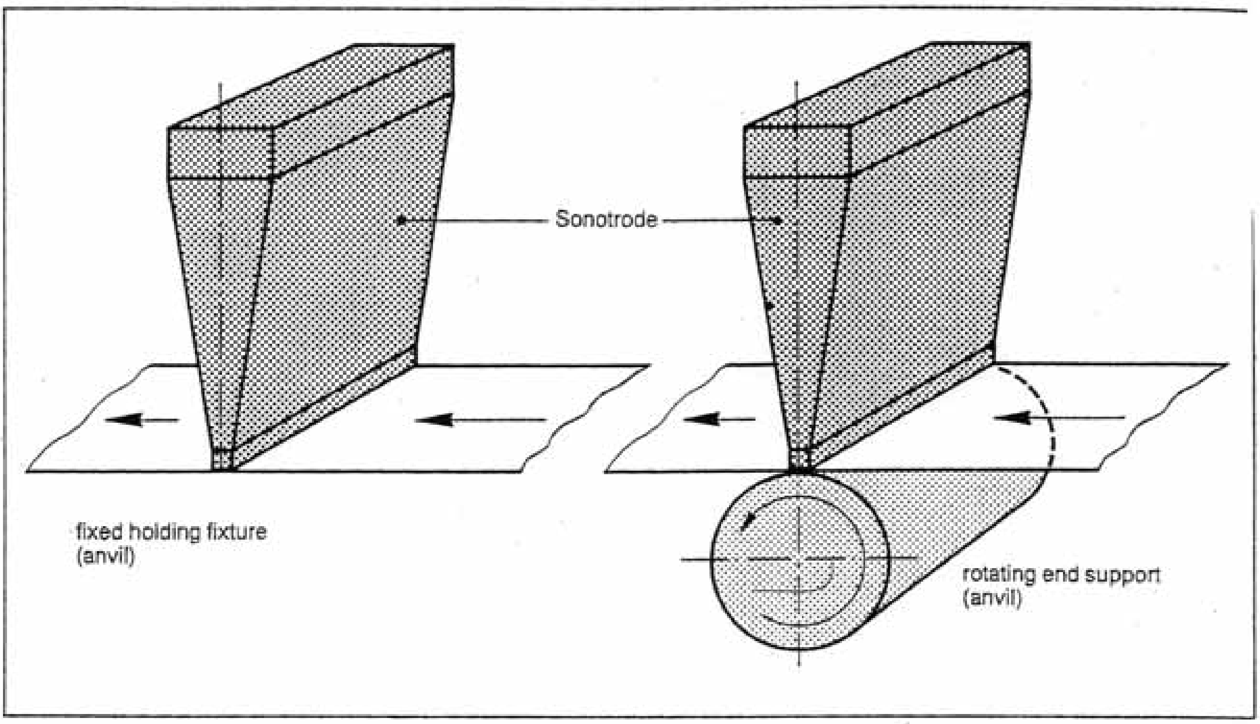


Figure 37: Ultrasonic seam welding non-continuously by line seam sonotrode.

8.1.8 Welding of coated cardboards or fabrics

It is possible to join plastic-coated cardboards or fabrics by means of ultrasonic welding (Figure 38). Here the ultrasonic energy penetrates the base material and welds the coating together. It is a good idea to groove the front surface of the sonotrode.

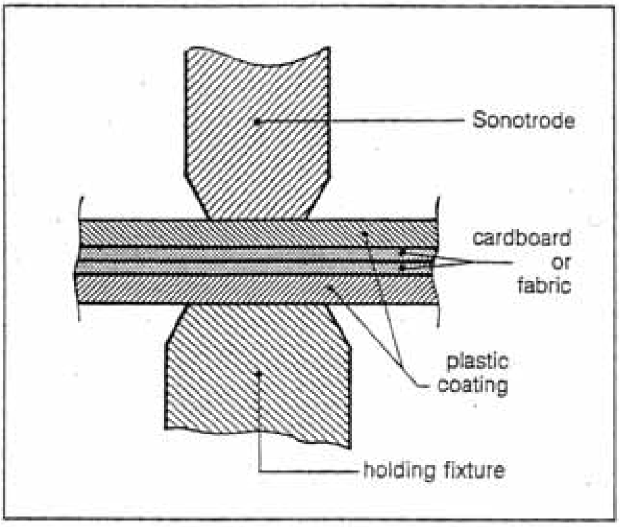


Figure 38: Arrangement in ultrasonic welding of coated cardboards or fabrics

8.2 Ultrasonic forming

Mouldings made of thermoplastics can be plasticised and formed ultrasonically. This is done for example in riveting, flanging and tamping. A particular advantage is that, as compared to forming with a warm die, the sonotrode remains cold during the forming process and hence at the same time performs the function of the cooling die.

In order to initiate plasticisation quickly it helps to block the moulding which is to be worked. If, however, the moulding co-vibrates in resonance, longer working times have to be allowed for. This can have an adverse effect on the quality of the moulding. In ultrasonic forming it should be taken into account that plasticisation first begins on the surface and penetrates from there to deeper zones. The zones which are to be formed should ideally be formed in a plasticised state. The forming conditions should therefore be tailored exactly to the plastic and the welding task. If not enough plasticised zones are formed, stress cracks and/or a weakening of the load capacity can be expected.

The usual ultrasonic welding equipment can be used for forming operations.

8.2.1 Riveting

As in ultrasonic welding, in ultrasonic riveting the sonotrode serves to transmit the mechanical vibratory energy to the stud. It is the riveting tool and is manufactured in accordance with the desired stud design and the number of pins which are to be riveted at one stroke. It is possible to carry out several rivetings with a sonotrode. Multiple-head installations are used in the riveting of large parts (e.g. dashboards in the car industry).

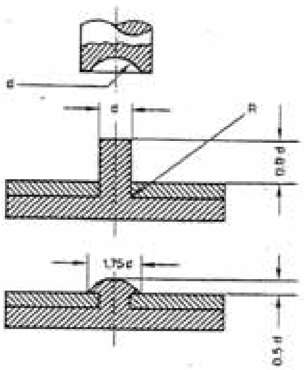
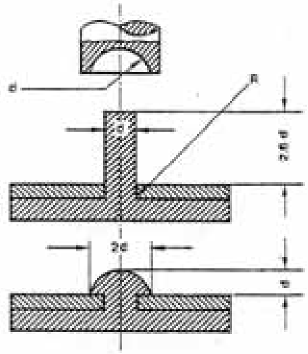
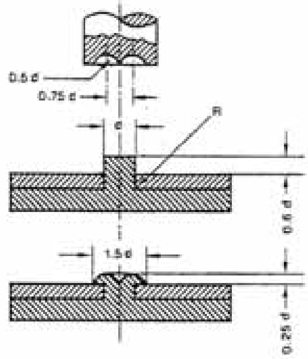
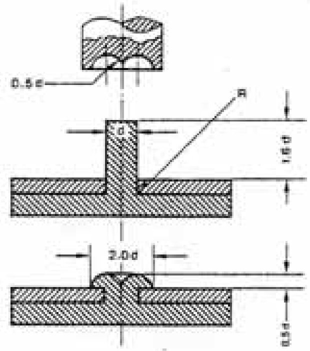
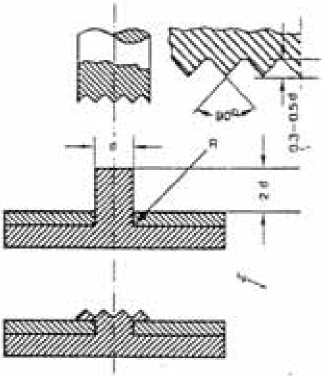
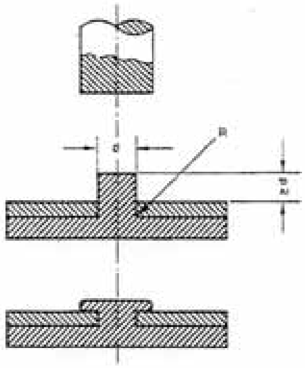
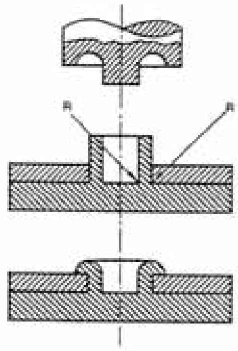
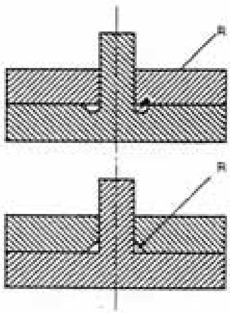
Diagram of shape of sonotrode, component and stud design	stud design	Diagram of shape of sonotrode, component and stud design	stud design	stud diameter
	A		B	d: > 1–5
	C		D	d: >2
	E		F	d: >0,5
	G		H	

Figure 39: Frequently used types of stud and stud diameters

The riveting time ('welding time') depends upon the material and the diameter of the stud. It is between about one and three seconds. In many cases it helps to work with the hold-down. The following points should be taken into account in riveting:

- ☐ adjustment of the excess length of the stud to the shape of the stud (the excess length of the stud should correspond to the volume of the stud)
- ☐ slow lowering speed of the sonotrode
- ☐ low pressure and generally higher amplitudes than is the case with ultrasonic welding
- ☐ holding time until the stud solidifies
- ☐ wear on the shape of the sonotrode (above all in the riveting of glass fibre reinforced plastics).

The stud is usually injected on the moulding. The fastening of the stud should not be sharp-edged but should have the largest possible radius. This prevents plasticisation or cracks in this area. Shaft designs as shown in figure 39 H have proved reliable.

The part which is to be riveted to the plastic is given an opening which fits the stud with a slight allowance for clearance. The excess length of the pin and the stud design depend upon

- ☐ the material which is to be riveted
- ☐ the desired firmness
- ☐ the dimensions of the stud
- ☐ the dimensional tolerances for a multiple rivet joint.

Figure 39 shows types of studs which are frequently used. Stud designs A and B are preferred for thin pins up to about 3 mm. Studs designs C and D have proved themselves particularly reliable. With these shapes the contact surface between sonotrode and rivet pin through the central tip, which must engage centrally, is at first very small. The ultrasonic energy passes through here. Stud design D is preferred on account of its good stability.

In the case of version E the front surface of the sonotrode is provided with a knurled pattern (cross-hatched). This shape of stud has proved its value for single and in particular for multiple rivet joints. The rivet zone is knurled over a large surface on the front surface of the sonotrode. In this way inaccuracies of positioning between the sonotrode and the rivet pin, as well as dimensional tolerances in the distance between several riveting positions, can be offset.

With a fairly large rivet pin diameter it is recommended, in particular in order to avoid sunk spots during the injection of the parts, that hollow pins (figure 39, version G) or several thin pins should be used.

For the riveting of glass fibre reinforced thermoplastics higher ultrasonic power is required than in the case with the same plastic without a glass fibre additive.

As riveting sonotrodes are subject to a relatively high degree of wear with glass fibre reinforced plastics, the work surface of the sonotrode must be designed so as to be wear-resistant.

With the riveting of the materials PA, POM, PETP and PBTP, as well as there being an optimum design of the shape of the stud, the riveting conditions must be specially adjusted. The use of the shapes C, D and E as shown in figure 39, as well as higher amplitudes and power outputs than with hard amorphous plastics, is preferred. The binding of the stud should have a sufficiently large radius (figure 39 H).

8.2.2 Flanging

As in metal working, moulded parts made of plastic can also be flanged. In this way plastic components can be joined to one another and in combination with materials of a different nature. According to the task to be performed, the sonotrode should be contoured on its work surface in order to plasticise and form edges, pins, projections or other fastening devices.

Ultrasonically produced flanges are particularly economical. The processing times are comparable to the usual cycles in the ultrasonic welding of mouldings. When glass parts are being flanged the sonotrode must not come into contact with the glass part.

Figures 40 and 41 contain examples of internal and external flanges.

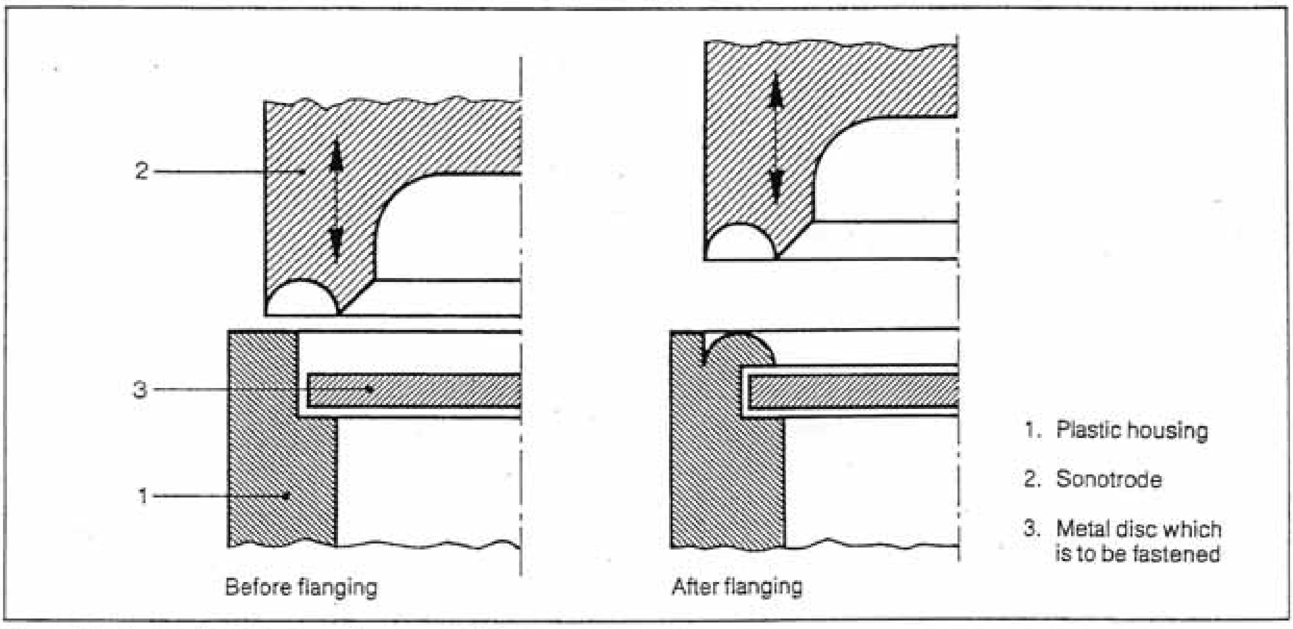


Figure 40: Internal flanging, fastening a metal disc in a plastic housing.

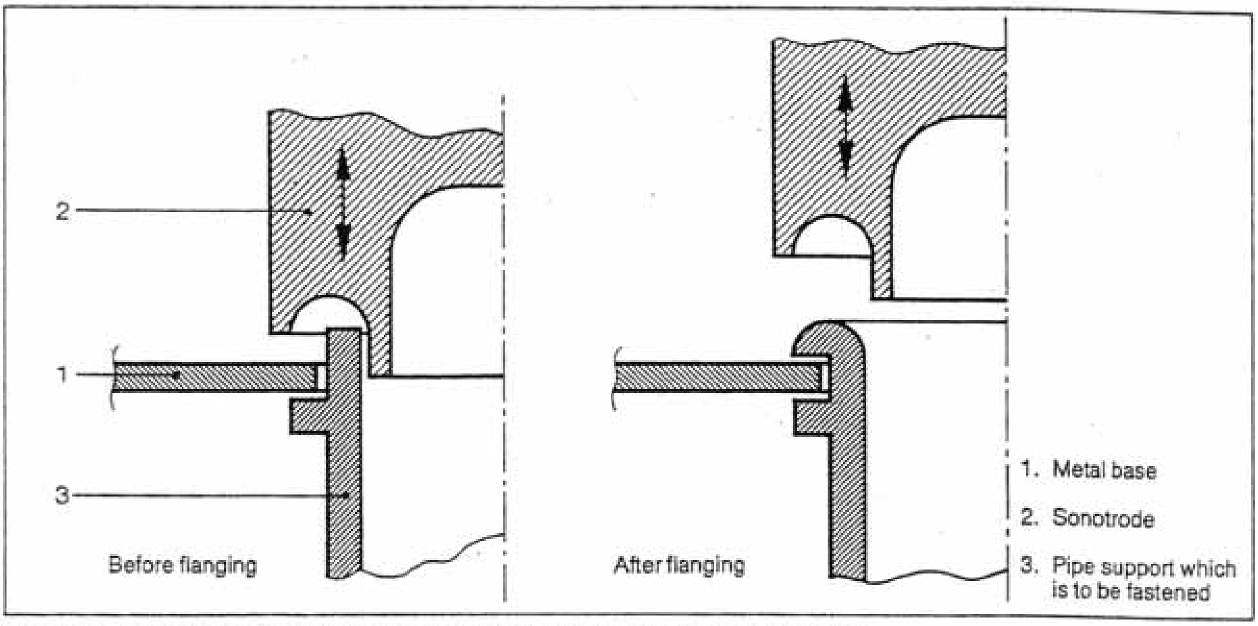


Figure 41: External flanging, fastening a plastic pipe support on the base of a container

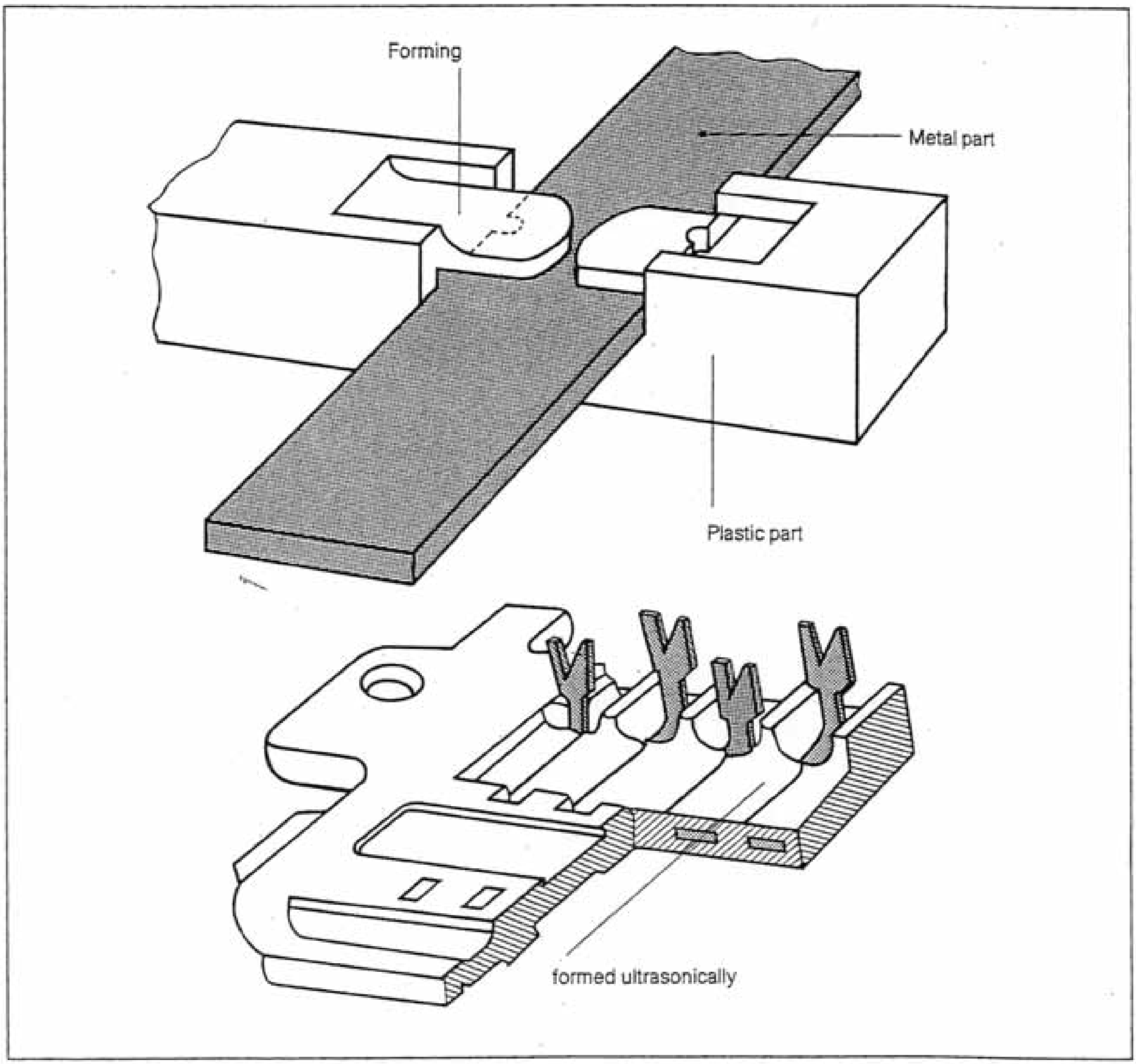


Figure 42: Examples of ultrasonic tamping.

8.2.3 Tamping

Ultrasonic tamping is a process similar to flanging for fastening materials of a similar or different nature to one another. The synthetic material plasticised by the sonotrode is pressed into pockets, recesses or drilled holes. This process produces an insoluble joint (figure 42).

8.3 Ultrasonic embedding of metal parts

Threaded inserts, grub screws or other metal parts can be ultrasonically embedded in thermoplastics.
Depending upon the size and shape of the metal parts, high torsional strengths and stabilities can be obtained.

Where there are favourable differences in height between the embedding levels several parts can be embedded simultaneously in one operation with an assembled sonotrode (figure 43). The lower sonotrodes have to be adjusted to the different joining levels.

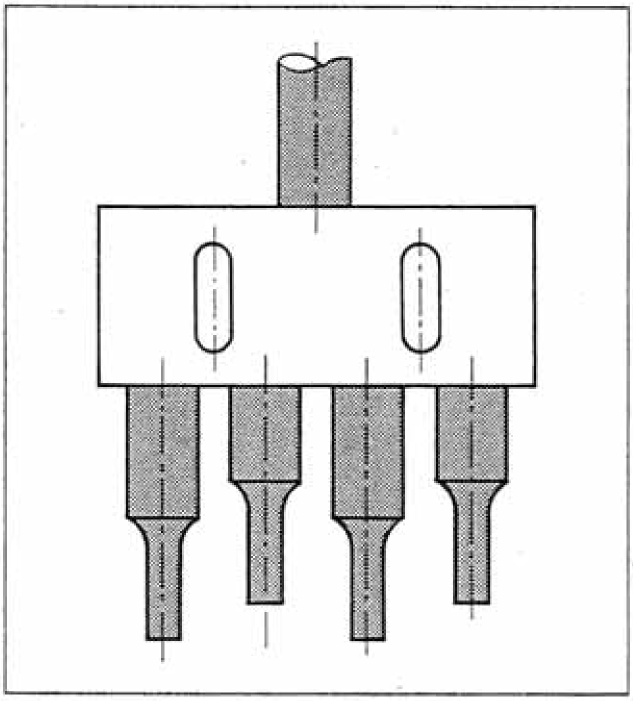


Figure 43: Sonotrode combination for embedding metal parts at different joining levels

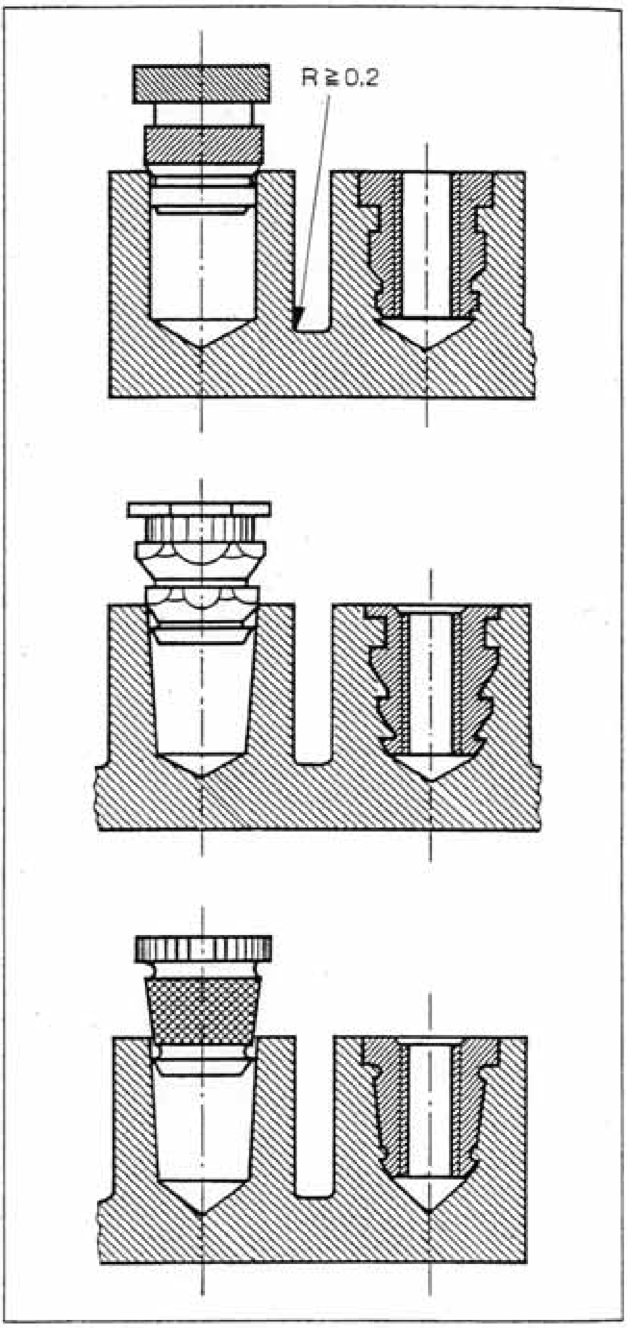


Figure 44: Plastic mouldings with injected eyelets for the insertion of metal parts.

With very long metal parts it is often an advantage to allocate the plastic part to the sonotrode and hold the metal part in the holding fixture.

Where the insertion holes in the plastic part are also injected in eye shapes, it should be borne in mind that markings can appear on the back, usually in the form of sunk spots. The ratio of the wall thickness of the eyelet to the wall thickness of the moulding stated by the producers of the raw material must be taken into account in such cases.

The following should be taken into consideration in order to obtain a stress-free embedding of the metal parts with a high torsional strength and stability.

The metal parts can be placed without going out of line by the drilling of a pilot hole which is about 0.1 - 0.2 mm larger in diameter than the metal part. The metal parts which are to be embedded must be kept sufficiently aligned.

The eyes should have a radius ≥ 0.2 mm at the junction with the plastic part (figure 44).

The insertion hole should be slightly smaller than the metal part which is to be embedded (Table 1).

Where conical metal parts are to be embedded in cylindrical insertion holes, about half of the metal part should drop into the insertion hole. The undersize of the insertion hole should be such that the volume of the mass which is plasticised during embedding is at least equal to the volume of the recesses or edges of the metal part.

For blind holes the insertion hole must be at least 2 - 3 mm deeper than the metal part to be embedded in order to absorb the displaced plastic melt.

Where high torsional strength and stability are required, the thickness of the wall for insertion holes in eyelets should be at least 1.5, and preferably > 2 mm. The recommendations of the producers of the raw material and the manufacturers of the machines and the metal parts should be adhered to. The amplitude should be as small as possible in embedding, so as to avoid stresses, the formation of cracks or destruction of the eyelets.

It is of advantage to place the sonotrode when it is vibrating, or to introduce the ultrasonic energy immediately after a very slight pressure build-up. The sinking speed should be low. The ultrasound should only be applied until the metal part is embedded. Metal abrasion is to be expected as a result of embedding.

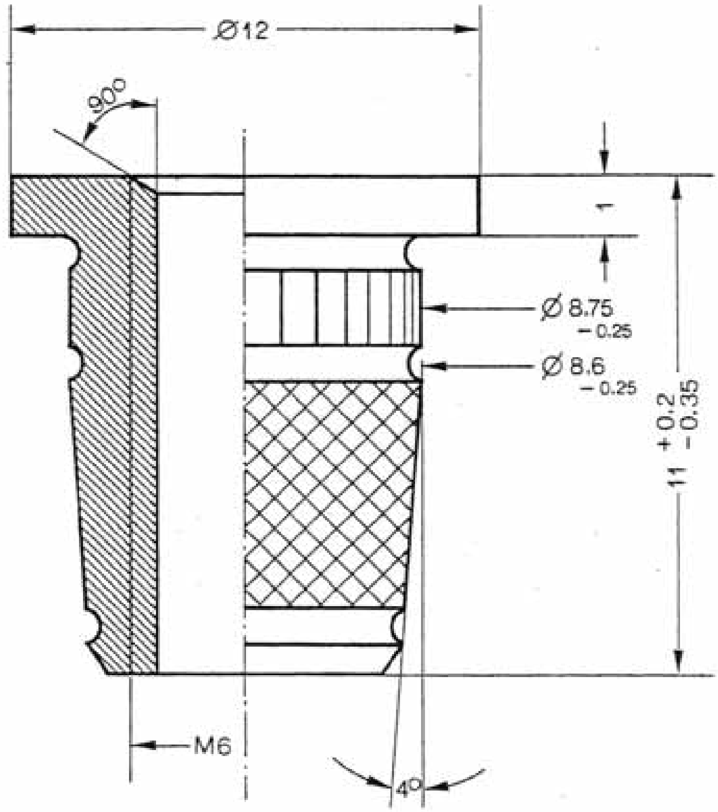


Figure 45: Threaded insert with collar.

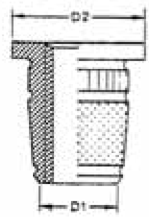
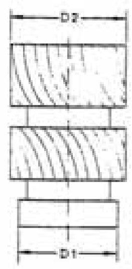
Metric thread	Length of bushing in mm	Diameter in mm D 1	D 2	Insertion hole in mm (rec. value)	Threaded bush 1
M3 M4 M5 M6 M8	5,5 7,5 9,0 10,0 12,0	4,0 5,2 6,4 7,7 9,7	4,7 6,15 7,35 8,75 11,3	4,3 5,65 6,85 8,25 10,8	
Metric thread	**Length of bushing in mm**	**Diameter in mm D 1**	**D 2**	**Insertion hole in mm (rec. value)**	**Threaded bus 2**
M3 M4 M5 M6 M8	5,8 8,2 9,5 12,7 12,7	3,9 5,5 6,3 7,9 9,5	4,7 6,3 7,1 8,7 10,2	4,0 5,6 6,4 8,0 9,6	

Table 1: Recommanded diameter of hole for insertion of threaded inserts 1 and 2.

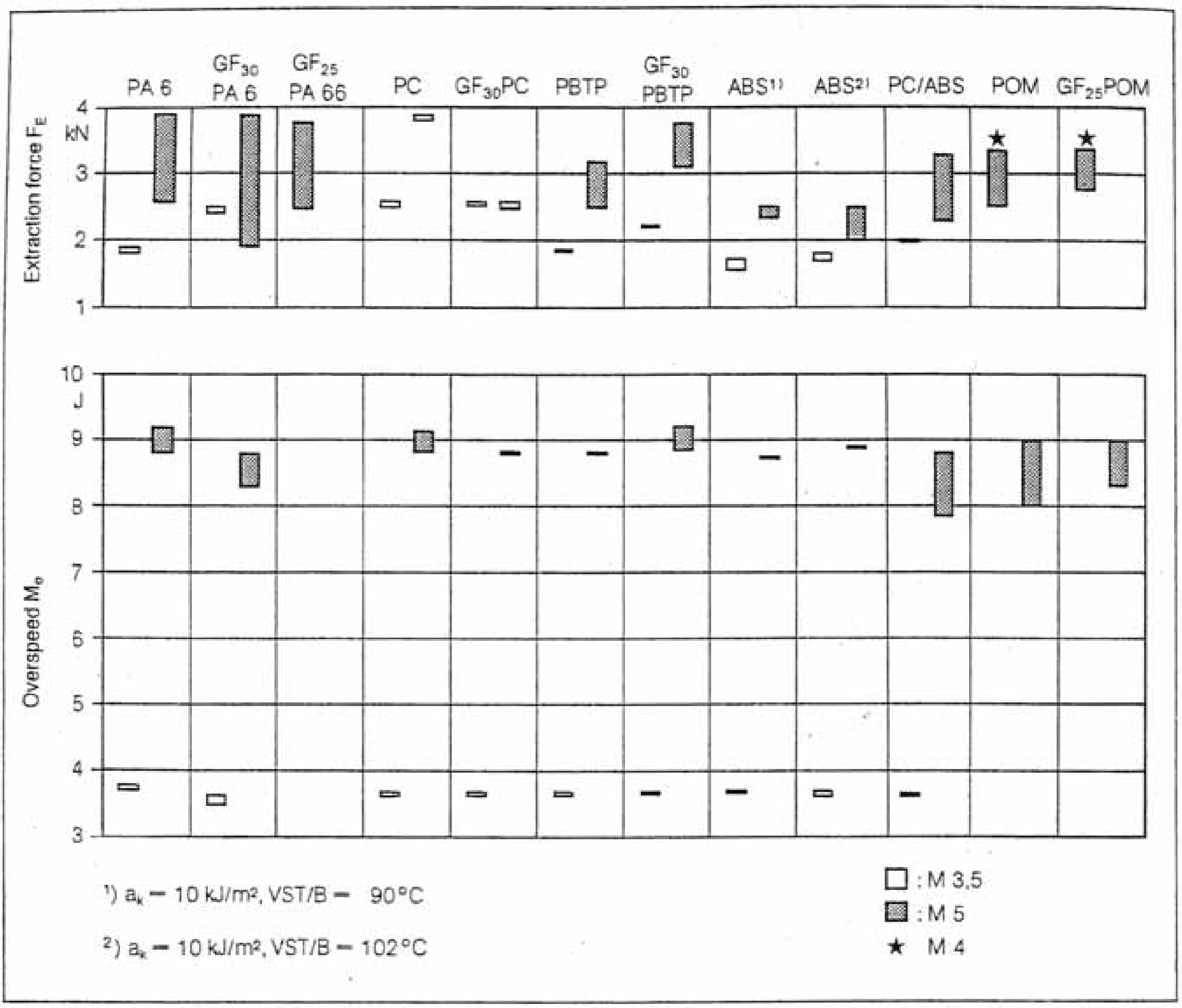


Table 2: Extraction forces and overspeeds of embedded threaded inserts M 3.5; M4 and M5.

In order to keep the tensile force on the threaded inserts low it is recommended that the threaded insert should be allowed to protrude about 0.1 mm over the surface of the plastic. In this way, in the event of bolting, the forces which are exerted are supported on the front surface of the insert and not on the plastic. Otherwise the insert and the welding surface are under a continuous tensile load. In the case of the threaded insert in figure 45 the protruding collar provides a support.

The rigidity that can be obtained with some thermoplastics is listed in Table 1. Lower or higher values can be attained according to the conditions under which the plastic parts are manufactured and the embedding conditions.

8.4 Ultrasonic separate-seam welding

Non-woven textile fabrics (fabrics and knitted fabrics) with a thermoplastic portion can be separated and hardened ultrasonically. The thermoplastic portion should be at least 65%.

Ultrasonic separation can be carried out continuously or in cycles. Separating is carried out by either the sonotrode or the holding fixture being designed as dies. The wear on the dies should be taken into account.

The advantages are: no fraying of the cutting edges.

8.5 Ultrasonic welding of non-woven textile fabrics (e.g. fabrics with mouldings)

Another special application is the welding of fabrics onto mouldings (figure 46). It is also possible, however, to join a fabric and a moulding when different plastics come together. Here the plasticised synthetic material penetrates the structure of the fabric and in this way a joint between fabric and moulding is obtained. It is advisable to provide energy directors on the moulding.

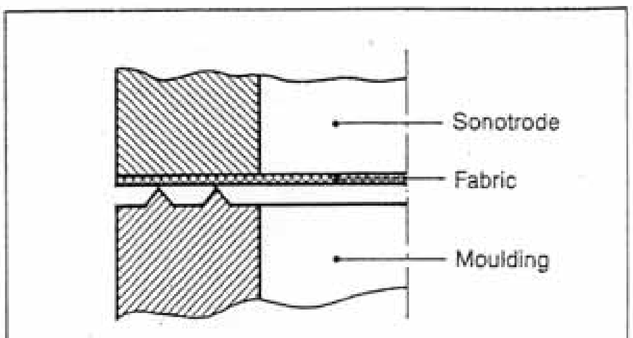


Figure 46: Arrangement for ultrasonic welding of fabrics and mouldings.

9. Sonotrode manufacture

9.1 General

The sonotrode serves as a means of transmitting the vibratory energy from the transducer (converter) to the joint surface, and also usually as a transformer for the mechanical amplitude.

As already described under point 3.2.2 'Sonotrode', the design and manufacture of a sonotrode requires special attention. Incorrectly manufactured sonotrodes impair the welding quality and can lead to the destruction of the vibrational system and to considerable damage to the generator.

Sonotrodes are manufactured predominantly by the manufacturers of ultrasonic equipment.

If the parameters, required frequency, transformation or speed ratio and lateral dimensions (l_o/D) are adhered to, sonotrodes with maximum lateral dimensions of 60 mm at about 20 kHz or 30 mm at 40 kHz can be made by the user himself. It is preferable to begin with the manufacture of stepped sonotrodes (figure 47a).

The length (l_o) of the sonotrode normally corresponds to half a wavelength $\lambda/2$ (figure 47a). For special applications sonotrodes with lengths several times $\lambda/2$ or combined $\lambda/2$ sonotrodes are also manufactured (figure 48).

Sonotrodes which on account of large lateral dimensions require slots (figure 49) should under no circumstances be made by the user himself unless he has sufficient basic knowledge about the construction of sonotrodes.

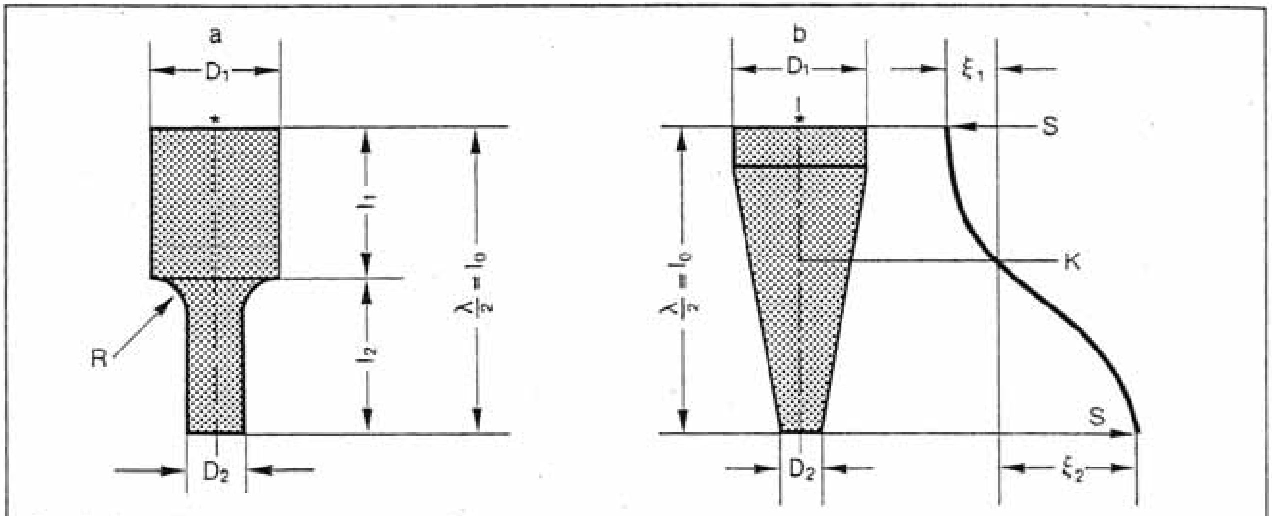


Figure 47: Sonotrode $\frac{\lambda}{2}$ = Standard version

a = stepped, b = conical

Cross-sectional variants:
Circle/circle Circle/rectangle Rectangle/rectangle

$\frac{\xi_2}{\xi_1}$ = Transformation ratio of the sonotrode

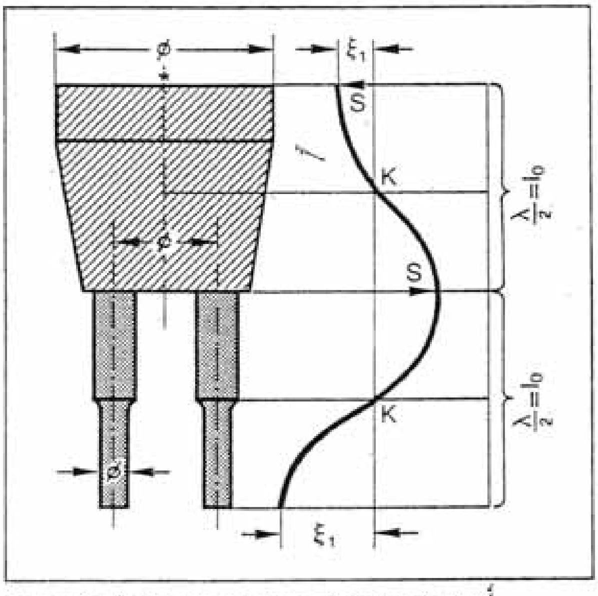


Figure 48: Assembled combined sonotrode 2 x $\frac{\lambda}{2}$

S = Anti-node oscillation
* = Connecting thread
K = Nodal point of oscillation
ξ = *Amplitude*

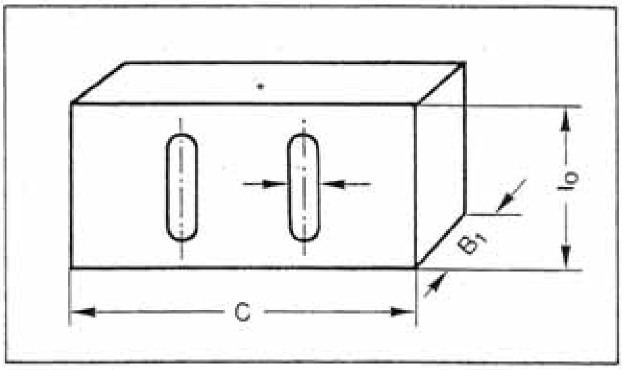


Figure 49: Sonotrode with rectangular form (with slots)

Material	Amplitude µm Values adopted in practice
Polystyrol (PS)	15 to 30
Polystyrol impact strong (SB)	20 to 35
Acryl, butadiene-styrol (ABS)	20 to 30
Stryol-acryl nitrile (SAN)	15 to 30
Polymethyl methacrylate (PMMA) injection mould	20 to 35
Modified (PPO)	25 to 40
Polycarbonate (PC)	25 to 40
Polyacetyl resin (POM)	40 to 50
Polyamide (PA)	35 to 55
Polyethyl enterephtalate (PETP)	45 to 55
Polynuthyl enterephtalate (PBTB)	40 to 50
Cellulose derivatives	25 to 35
PVC hard	20 to 40
PVC soft	25 to 40
Polyethylene (PE)	25 to 60
Polypropylene (PP)	30 to 60

Table 3: Recommended values for the amplitude in ultrasonic welding in the near field. The amplitudes can differ with modified materials.

Material	Sound velocity v_0 $\left(\frac{m}{s}\right)$	Variations $\left(\frac{m}{s}\right)$
Titanium alloy TiAlV64	4900	± 100
Aluminium alloys AlCuMg2 AlCuMGPb	5100 5000	± 100 ± 100
Aluminium	5100	± 200
Monel annealed and quenched	4350	± 150
1550 steel (RT 11) tempered	5250	± 50
Ferrotitanite WFN hardened	6950	± 150

Table 4: Sound velocity of various sonotrode materials

9.2 Sonotrode materials

As very high amplitudes predominate in the welding of plastics and forming (Table 3), the stress load on the sonotrode is considerable. It means that only materials with a high alternating impact strength and low absorption can be used.

The alloys titanium (TiAlV64) and aluminium (AlCuMg2) have proved to be best. Both these alloys have great stability and with distortion-free operation can withstand a load up to 40 µm amplitude at 20 kHz. At higher frequencies lower amplitudes are employed.

The sound velocity of the following sonotrode materials can be seen in Table 4.

Titanium alloy TiAlV64:
Large series, with coating also suitable for glass fibre reinforced plastics.

Aluminium alloy AlCuMg2:
Large series, can likewise be coated.

AlCuMgPb:
Experimental sonotrodes, small series.

Monel:
Up to an amplitude of 20 µm hard metal plates or hard metal pins can be soldered in.

1550 steel tempered (RT 11):
Mainly for embedding metal parts in plastics.

Ferro-titanite:
Extremely non-abrasive, therefore particularly well-suited to the riveting of glass fibre reinforced plastics.

9.3 Shapes of sonotrode

Sonotrodes can be manufactured in various shapes and dimensions. In practice the following shapes have proved particularly reliable:

1. Stepped form with circular section (figure 47a)
2. Conical form with circular section (figure 47b)
3. Stepped form with square and rectangular section (figure 49)
4. Exponential form

9.4 Sonotrode parameters

Sound velocity	v
Wavelength/2 $= \frac{\lambda}{2}$	l_0
Frequency	f
Input diameter of the sonotrode with circular section (booster)	D_1
Output diameter of the sonotrode with circular section (to the moulding)	D_2
Input surface of the sonotrode	A_1
Output surface of the sonotrode	A_2
Output diameter of the booster (Coupling surface to the sonotrode)	D_3
Output surface of the booster (Coupling surface to the sonotrode)	A_3
Output amplitude of the booster	$\hat{\xi}_3$
Input amplitude of the sonotrode	$\hat{\xi}_1$
Output amplitude of the sonotrode	$\hat{\xi}_2$
Transformation or speed ratio	β

The following values should be indicated by the manufacturer of the instrument and strictly observed:

Sound frequency	$f \pm$ tolerance
Amplitude of the booster	ξ_3
Output surface or output diameter of the booster	A_3 or D_3

9.5 Determining the sound velocity

If the sound velocity of the sonotrode material is not known, it can be established with the measuring device (figure 50), the frequency of a 130 mm long sample without rolling scale or draw scale being measured. The sound velocity is obtained from the function

$$v = 2 \cdot l \cdot f$$

in which the function $l \geqslant 3 \cdot D$ must be fulfilled, as sound velocity depends upon shape.

By coordinating a cylinder with a diameter of about 40 mm made of the sonotrode material with the unknown sound velocity as given under section 9.9 the sound velocity and the resonance length can be established.

9.6 Determining the length of stepped sonotrodes

Stepped sonotrodes are made up of

$$l_o = l_1 + l_2$$

(figure 47a).

The junction to the smaller cross-section is on the nodal plane. The junction should have a radius, as there is a danger here of cracks forming. With sonotrodes with maximum cross-sectional dimensions of 60 mm a R = 10 mm has been found to be satisfactory. The length l_o can be calculated from the function for the simple cylindrical body:

$$l_o = l_1 + l_2 - k_1 \cdot \frac{v}{4 \cdot f} + k_2 \cdot \frac{v}{4 \cdot f}$$

The correction factors k_1 and k_2 depend upon the give sonotrode cross-section.

Transformation ratio $\beta = \frac{A_1}{A_2} = \left(\frac{D_1}{D_2}\right)^2$

The sound velocity v can be seen from Table 4 and l_1 or l_2 in Table 5. To make it easier to coordinate sonotrodes by shortening their lengths, the established length of the sonotrode should be increased by 2-3 mm. With increasing practical experience and correct use of Table 5 this additional amount can be reduced or dispensed with.

9.7 Calculating the length of a rotationally symmetical sonotrode with an e-function

Exponential form

$$l_o = \frac{v}{2 \cdot f} \times \sqrt{1 + \left(\frac{l_n D_1/D_2}{\pi}\right)^2}$$

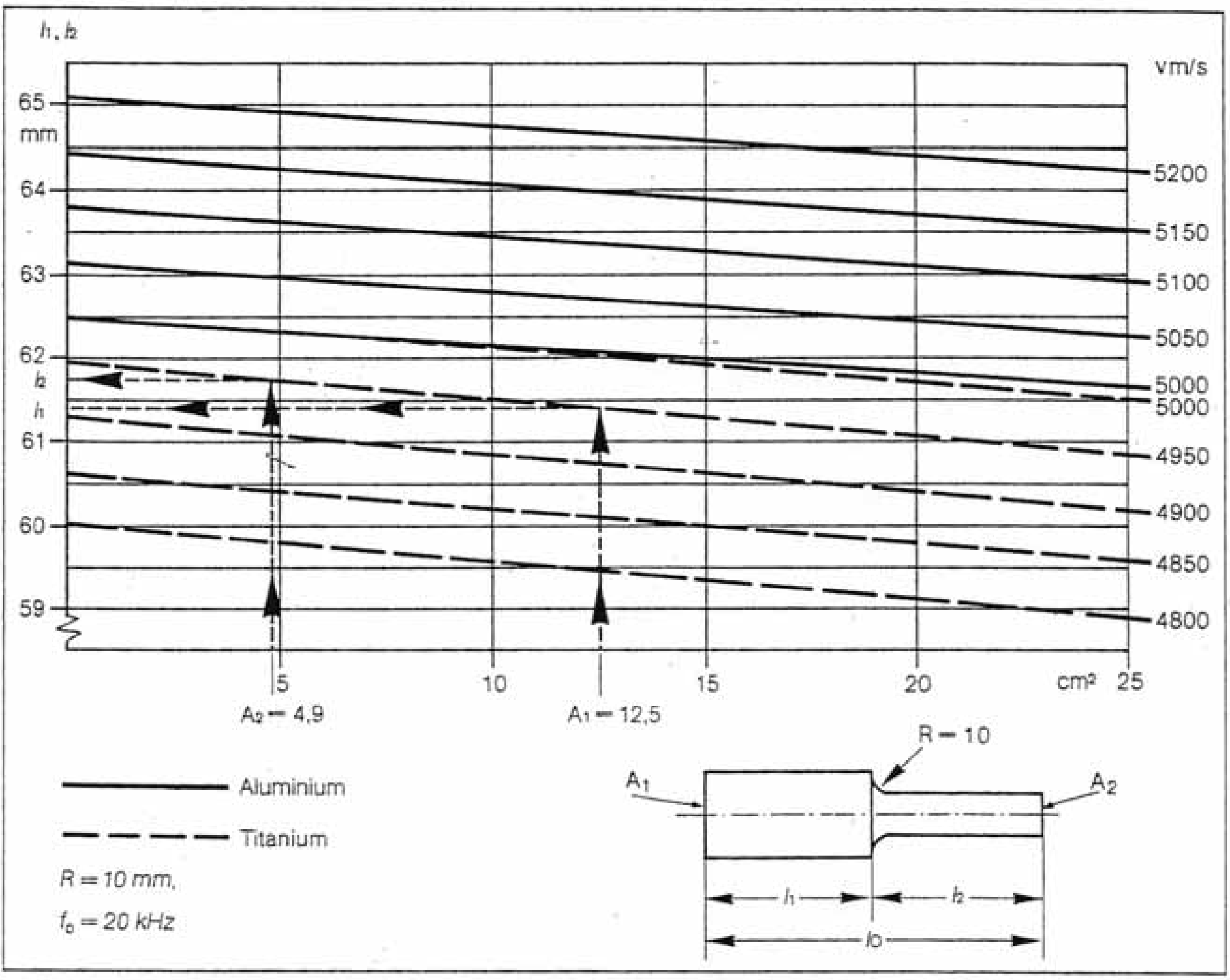


Table 5: Determining diagramatically l_1 and l_2 with stepped sonotrodes.

The e-function sonotrode is very good in terms of sound, but expensive to manufacture and is therefore only used to a small extent, especially as most sonotrodes are used in practive with a speed ratio smaller than 1 : 4.

Transformation ratio $\beta = \sqrt{\frac{A_1}{A_2}} = \frac{D_1}{D_2}$

9.8 Establishing the length of a conically shaped sonotrode with rotationally symmetrical and rectangular cross-section

The conical sonotrode is the most difficult to calculate of the three shapes mentioned. In practice, therefore, the function of the exponential sonotrode is generally used and multiplied by a safety factor of 1.1. Table 6 makes it possible to determine the length of the cone for different sound velocities with diametrical ratios up to 1 : 4 in the case of sonotrodes

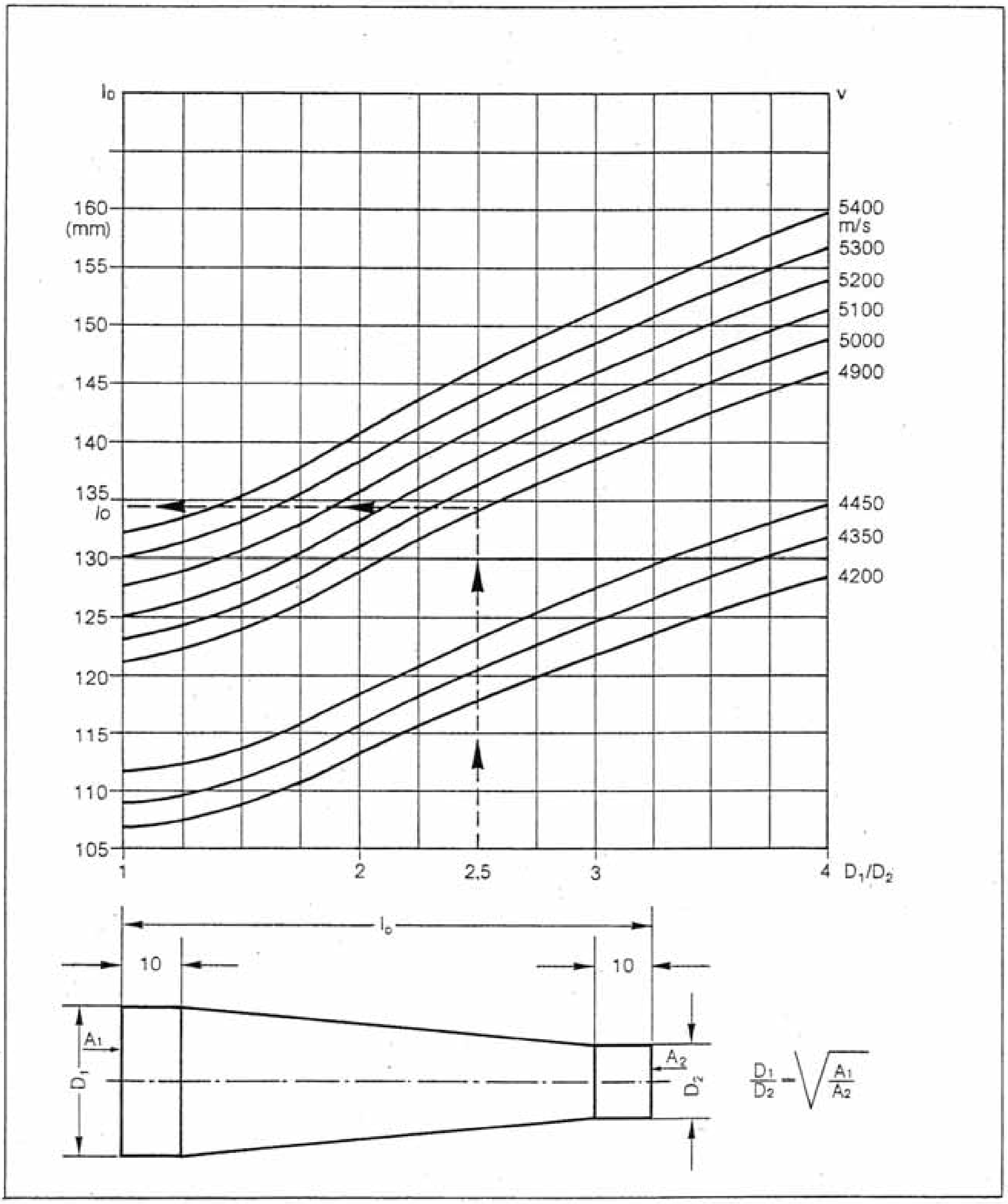


Table 6: Diagram for establishing the length of conical sonotrodes depending upon diameter ratio and sound velocity f = 20.0 khz. The above formula applies to designs with rectangular cross-sections. Insertion thread M16 x 1.5; depth of thread 15 mm. It is necessary to have additional length of 3 mm for checking.

with threads M 16 x 1.5 and thread depths of 15 mm. With larger thread diameters there should be additional length on the thread side.

Transformation ratio

$$\beta = \sqrt{\frac{A_1}{A_2}} \cdot \cos \frac{\omega \cdot l}{v} + \frac{v}{\omega \cdot l} \left(1 - \sqrt{\frac{A_1}{A_2}}\right) \sin \frac{\omega \cdot l}{v}$$

9.9 Tuning the blank sonotrode

The frequency of the blank sonotrode is as a result of added material of 2-3 mm generally 0.5 to 1 kHz below the desired resonant frequency. The sonotrode reaches the required frequency as a result of being shortened and remeasured several times. The sonotrode measuring device is used to measure the natural frequency (figure 50). It consists of an RC generator, a measuring transducer and frequency indicator. Sonotrode measuring devices are also marketed as compact devices with built-in RC generator.

For measuring, the sonotrode is placed as shown in figure 50 on the measuring transducer or in the case of other types of instrument screwed to the measuring transducer, which is connected to the RC generator. The probe (vibration receiver) coupled with the tuning instrument touches the tip of the sonotrode. The frequency range in which the sonotrode is assumed to lie must be gone through on the RC generator. The resonant frequency has been obtained when the maximum amplitude reading is observed on the tuning instrument or when the indicator reading of the instrument is observed on the compact instrument.

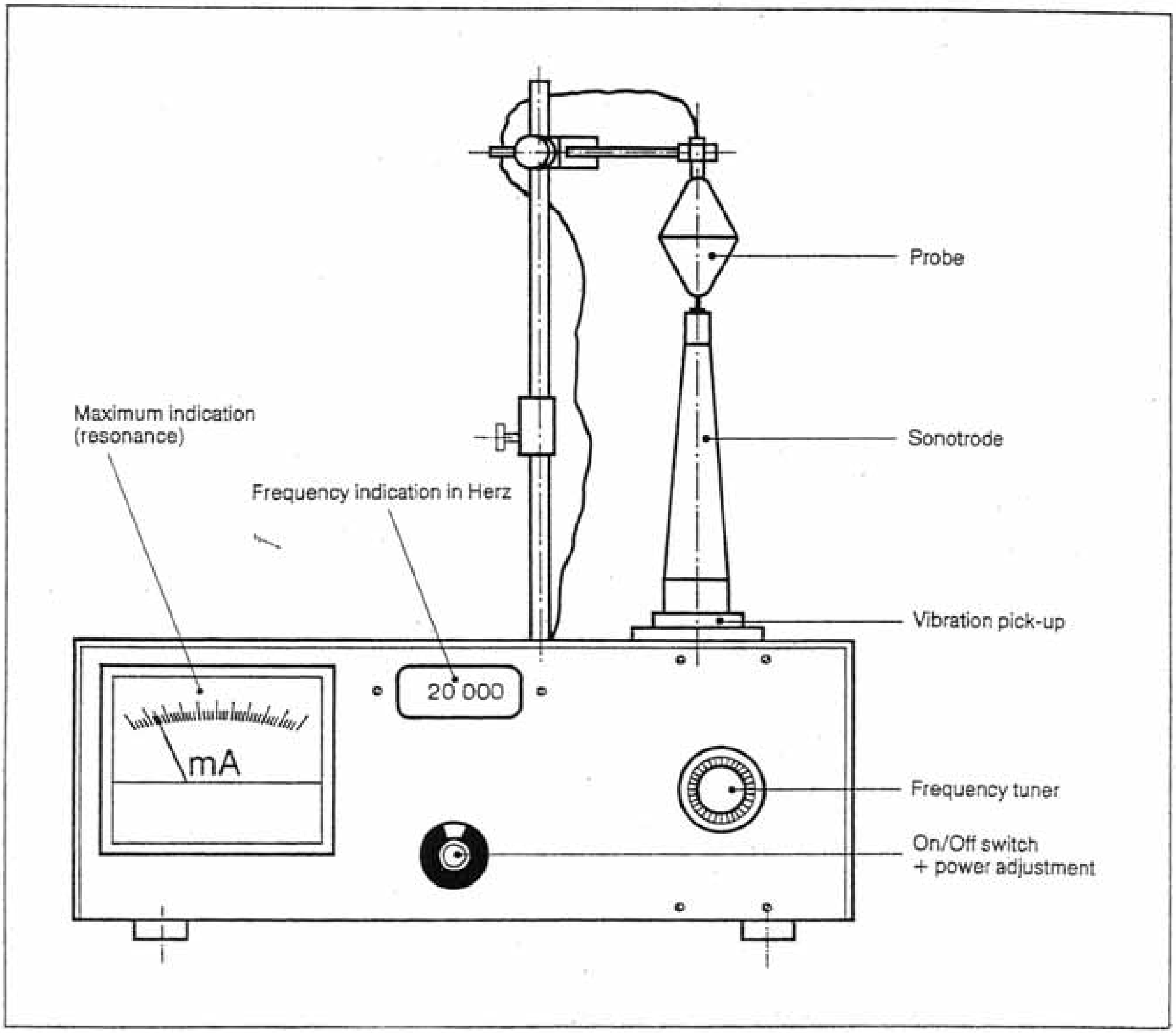


Figure 50: Sonotrode measuring device

9.10 Practical example

Calculation of a sonotrode made of titanium for a moulding made of polystyrol with a diameter of 25 mm.

Data given by the manufacturer of the machine:
Amplitude of the booster $\xi_3 = 10\ \mu m$
Coupling diameter of the booster $D_3 = 35$ mm
Working frequency $f = 20$ kHz $\pm$ 0,2 kHz

Required amplitude for the moulding made of polystyrol, Table 3, page 34, $\xi_2 = 25\ \mu m$ (selected)

for an ideal coupling surface: $\xi_1 = \xi_3$

Amplitude transformation $\beta = \frac{\xi_2}{\xi_1} = \frac{25\ \mu m}{10\ \mu m} = 2{,}5$

1. Sonotrode with stepped shape (circular section) diagrammatic solution, Table 5, page 35.

$$\beta = \frac{A_1}{A_2} = \left(\frac{D_1}{D_2}\right)^2$$

$$D_1 = \sqrt{\beta \cdot D_2^2} = \sqrt{2{,}5 \cdot 25^2} = 39{,}53 \sim 40\ \text{mm}$$

D_1 = 4 cm
A_1 = 12.57 cm²
D_2 = 2.5 cm (adapted to the part)
A_1 = 4.9 cm²
v = 4950 m/s for the titanium selected, Table 4, page 34
l_1 = 61.4 mm Table 5, page 35
l_2 = 61.7 mm Table 5, page 35
l_0 = $l_1 + l_2$
l_0 = 61.4 + 61.7 = 123.1 mm
+ allowance of 2 mm at l_2

Arithmetical solution

$$l_0 = K \cdot \frac{v}{2 \cdot f} = \frac{4950}{2 \cdot 20} = 123{,}75\ \text{mm}$$

+ allowance of 2 mm

The correction factor K is adopted with 1.

2. Conical form

Diagram solution, Table 6, page 36

Aproximate calculation of the transformation ratio

$\beta \approx \frac{D_1}{D_2}$ only applies for small diameters.

The divergence for $\frac{D_1}{D_2} = 3$ is approximately 10% and at $\frac{D_1}{D_2} = 5$ is approximately 30%.

$$\beta = \frac{\xi_2}{\xi_1} = \frac{25\ \mu m}{10\ \mu m} = 2{,}5$$

D_2 = 25 mm (adapted to the part)
D_1 = $\beta \cdot D_2$
D_1 = 2.5 · 25 = 62.5 mm
l_0 = 134 mm + 3 mm allowance (Table 6)

In the example presented the stepped shape is chosen, as less material is required and the coupling surface is completely covered. The sonotrodes should be attunded to the required frequency as described in point 9.9.

9.11 Reworking sonotrodes

When sonotrodes which have already been attuned are reworked on the front surface (adjustment of the front surface of the sonotrode to the outline of the moulding) the frequency f_0 becomes higher. Afterwards the sonotrode can be outside the permissible tolerance and may no longer be operated on the ultrasonic welding instrument. It is possible to reduce the frequency again slightly.

9.11.1 Frequency correction

The frequency should be increased:
- ☐ Shortening of the complete length (applies to all shapes of sonotrode). Attention: not linear!

The frequency should be reduced:
- ☐ Conical shape (figure 51), exponential form, cylinder – making a groove at the centre of gravity.
- ☐ Stepped shape (figure 52) – shortening of length l_1.
- ☐ Square or rectangular shape – widening of the slots b_1 (figure 49).

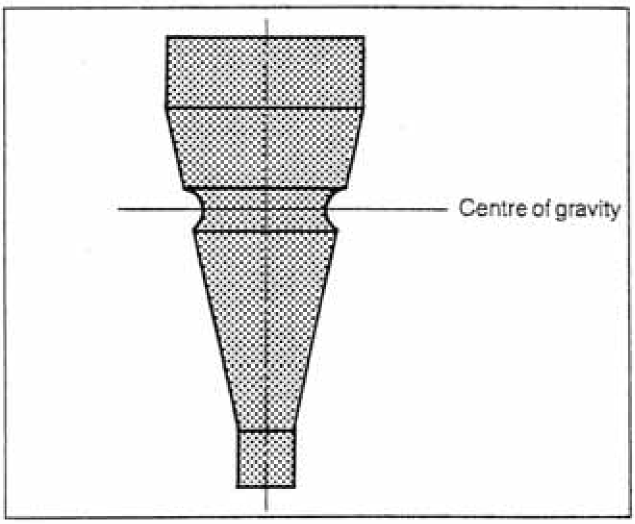


Figure 51: Reduction of the resonant frequency of a conical sonotrode by a groove at the centre of gravity.

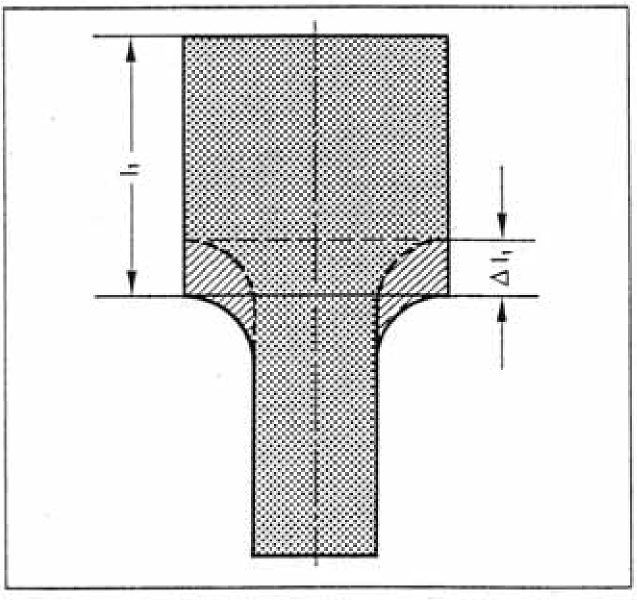


Figure 52: Reduction of the resonant frequency of a stepped sonotrode (stepped cylinder) by shortening length l_1

10. Safety measures for ultrasonic assembly

The accident-prevention regulations, the noise control measures (see section 11) and the operating instructions of the manufacturers of the equipment should be observed when ultrasonic installations are being operated.

Ultrasonic welding equipment is subject to the requirements of the law on high frequency and has to be registered with the German Federal Post Office.

Contact with vibrating sonotrodes should be avoided. Direct action of ultrasonic energy on the skin causes the tissue to be heated and destroyed. Experience hitherto has shown that power densities up to 2 W per cm^2 are not dangerous if the ultrasonic energy does not continually strike the same part of the skin.

11. Noise-control measures

11.1 Preliminary remarks

Irritating or harmful noise can occur during ultrasonic thermoplastic assembly. Where necessary one should therefore check that the accident-prevention regulation on 'Noise' and paragraph 15 of the Decree on Workplaces are observed /1/2/. These lay down that individuals may be exposed to an estimated level in accordance with DIN 45645/3/ of at most 90 dB (A). The estimated level refers to noise within the hearing range of the human ear. According to DIN 1320/4/ this range lies between 16 Hz and 16 kHz. Ultrasonic installations, however, also emit sound at higher frequencies which, although they cannot be heard, can be registered by a sound level meter. When the assessed level is being measured the proportion within the audible sound range should therefore be separated from that in the ultrasonic range /6/. This is not possible with every measuring instrument.

11.2 Measuring procedure

As yet there is no binding regulation which deals clearly with the measuring of the working sounds of ultrasonic equipment. In /7/ Christ describes how the use of a 1" standard microphone is sufficient for separating the ultrasonic proportion. The estimated level is obtained accordingly from the A-assessed sound level at ear level of the operator obtained in time in the course of several work cycles; the average over a period of time is most simply obtained with an integrating sound level meter. The upper frequency level of 1" microphones ends differently, depending on the manufacturer, in the range of about 20 kHz. Higher frequencies are largely suppressed by the microphone. This method is therefore suitable for measuring ultrasonic equipment with an operating frequency clearly above the upper frequency limit of the microphone. When ultrasonic equipment with an operating frequency of about 20 khz is being measured, excessively high estimated levels are measured on account of the upper frequency limit of the microphone.

In /8/ Noé reports on industrial measurements carried out on a whole number of ultrasonic welding apparatuses. The results show that in the audible range the sonic proportions at half the operating frequency of the ultrasonic installations determine the noise level. Noé therefore suggests a measuring procedure in which account is taken only of the proportion which can be registered with an octave filter of the middle frequency 8 kHz. When the octave filter of the middle frequency 8 kHz is used the sound level meter registers a frequency range of 5.6 kHz to 11.2 kHz. This measuring procedure can thus be used for ultrasonic installations with an operating frequency of the upper audible limit (16 kHz according to DIN 1320). When loud sounds below 6.5 kHz occur this proportion should likewise be taken into account by the measuring of the lower octave bands.

As these accounts show, both measuring procedures have their limitations. The problem could easily be solved by the use of a low-pas filter with a limiting frequency of 16 kHz and a high edge steepness designed for ultrasonic equipment. (A manageable measuring instrument of this kind is not yet sold on the market, but is already being developed and tested.

11.3 Concluding remarks

Where an impermissibly high level of noise in the audible range occurs in ultrasonic assembly, experience has shown that a remedy can always be provided by the transducer, intermediate piece, sonotrode and mouldings being partially or completely enclosed /9/. In particular the non-audible proportion of the ultrasound is reduced to an acceptable level as a result of covering. Where necessary, it is recommended that in each particular case the application of the noise-control measures should be checked with the manufacturer of the machine.

With regard to the non-audible proportion of the ultrasound Dr. K. Brendel of the Physikalisch-Technische Bundesanstalt in Braunschweig reports in /5/ on an international working party of the World Health Organisation (WHO). The view of the working party is as follows:

"Up to ultrasonic levels of 120 dB no loss of hearing capacity or other physiological changes would seem to occur in the individuals concerned. With regard to the complaints which have increasingly been made recently about headaches, indisposition and dizziness as a result of high ultrasonic intensities in the air, the view was expressed that the relatively high levels of harmonic components in the audible range can be regarded as the cause of this."

As high frequencies can be more easily suppressed than low ones, a noise-control measure for the audible range always results in a considerable reduction of the non-audible ultrasonic proportion.

11.4 Suggested reading on noise-control measures

/1/ Arbeitsstättenverordnung v. 1.5. 1975
§ 15 – Schutz gegen Lärm

/2/ Unfallverhütungsvorschrift „Lärm" des Hauptverbandes gewerblicher Berufsgenossenschaften
in Ausgabe vom 1.12.1974

/3/ DIN 45 645 4/1977
Einheitliche Ermittlung des Beurteilungspegels für Geräuschimmission am Arbeitsplatz

/4/ DIN 1320 10/1969
Akustik; Grundbegriffe

/5/ PTB-Mitteilung 87 (1977) 4 S. 319
Working Group on the Health Aspects of Exposure to Ultrasound Radiation

/6/ DIN 45 633 3/1970
Präzisionsschallpegelmessen
Blatt 1: Allgemeine Anforderungen

/7/ Christ, E.
Geräuschmessungen an Ultraschall-Schweißmaschinen
Die Berufsgenossenschaft (1977) 11 S. 505-507

/8/ Noé, E.-L.
Messen der Arbeitsgeräusche beim Schweißen, Löten und Reinigen mit Ultraschall
Schweißen und Schneiden 29 (1977) 5 S. 183-185

/9/ Christ, E.
Geräuschminderung an Ultraschall-Schweißmaschinen
Die Berufsgenossenschaft (1977) 11 S. 508-511

/10/ Acton Ultrasonics, Jan. (1976) S. 42

/11/ DIN 57 411 T. 1

/12/ VDE/0411 T. 1

/13/ I. Veit
Wirkung von Ultraschall auf das Gehör, Bestandsaufnahme
Forschungsbericht Nr. 231

/14/ I. Veit
Betrachtung über die bekannten Wirkungen von Ultraschall auf das menschliche Gehör
Zeitschrift für Lärmbekämpfung 27. 188 192 (1980)

12. Areas of application

The examples given in the following areas of application have in some cases been applied in practice for many years (although it is not claimed that this is an exhaustive list).

12.1 Electrical engineering, electronics, lighting engineering, communications

Welding:
Plugs, cable plugs, pull-reliefs, connecting reeds, for plug housings, reels, bobbins, contact parts, fluorescent tube holders, automatic cut-outs, switching relays, plug mouldings, printed circuit boards, cut-out boxes, injections moulded bar ledges on extruded cable shafts, cable drums, lamp housings, arc chambers, light barriers, torch housings, limit switches, signal lamps, telephone receiver – earpiece – separator plug.

Riveting:
Voltage distributors, metal contacts in cable plugs, fuse switches, printed circuit boards, plugs.

Flanging, tamping:
Wire mountings, metal parts in contact housings, torch batteries, pull-reliefs, connecting reeds in plug housings, bobbins with soldering connections, plastic discs in metal wheels.

Embedding:
Contact wires in circuits, threaded inserts in housings.

12.2 Radio, Phono, TV, Video

Welding:
Cassettes for recorders, parts for video and tape recorders, loudspeaker enclosures, headphones.

Riveting:
Pick-up head for record player.

Embedding:
Threaded inserts in chassis for radio telephone equipment.

12.3 Photography, cinema, optics

Welding:
Transparency frames, developing boxes, film reels, pocket cassettes, flash-light cubes, camera and cine camera housings, housing parts of overhead projectors, binocular housings.

Riveting:
Chassis for slide and film projectors.

Embedding:
Chassis for slide projectors.

12.4 Engineering, precision engineering, installation, office equipment

Welding:
Inspection glass sealings, damp-proof insulations, water separators, mixing valve controls, roller blind controls, instrument handles, clock housings, ink cartridges, propelling pencils, ball-point pens, pens, typewriter covers, cartridges for Indian ink pens.

Flanging:
Discs for gaming machines, plastic discs in metal wheels, ballbearing and roller-bearing separators.

Riveting:
Pliers, typewriter golf balls.

12.5 Household appliances

Welding:
Housings, handles, ascending pipes and metal bases with plastic rings in coffee pots for coffee-makers, handles and water containers for electric irons, deep-drawn refrigerator trays with compartments, filters on frames for extractor hoods, functional parts for food processors, hair-dryers, housings, nozzles and accessories for vacuum cleaners, cigarette-lighters.

Flanging:
Coffee filters (fabric or metal strainers)

Embedding:
Bearing bush in hair dryer fan wheel.

12.6 Transport

Welding:
Reflectors, headlamp parts, rear lamps, rear reflectors for bicycles, warning triangles, street marking posts, sun vizors, interior and exterior mirrors for motor vehicles and motor bikes, glove compartment covers, buttons and switches, ventilator nozzles, dashboards, storage compartments, panelling vizors, motorcar and lorry emblems, horn housings, electrical parts for cars, valves for cooling fluid systems, corners of bumpers, safety-belt locks, safety-belts, fuel filters, radio screens, accessories for central locking mechanism.

Riveting:
Dashboards, instrument board frames, functional parts for door locking devices.

Flanging:
Interior and exterior mirrors, endcovers on Bowden wires, fan blades, adjusting levers for ventilator flaps.

Embedding:
Threaded bushes and pins in dashboards, steering-column panelling.

12.7 Furniture trade

Welding:
Legs, buttons and handles for furniture.

Riveting:
Welding functional parts.

Embedding:
Threaded inserts and grub screws for furniture parts.

12.8 Sport, leisure, hobbies, toys

Welding:
Ski bindings, skiing glasses, toy figures, parts for toy housings, train sets, toy cars, etc., watering cans.

Riveting:
Pocket-knife handles.

12.9 Packaging, transport, medical equipment, cosmetics

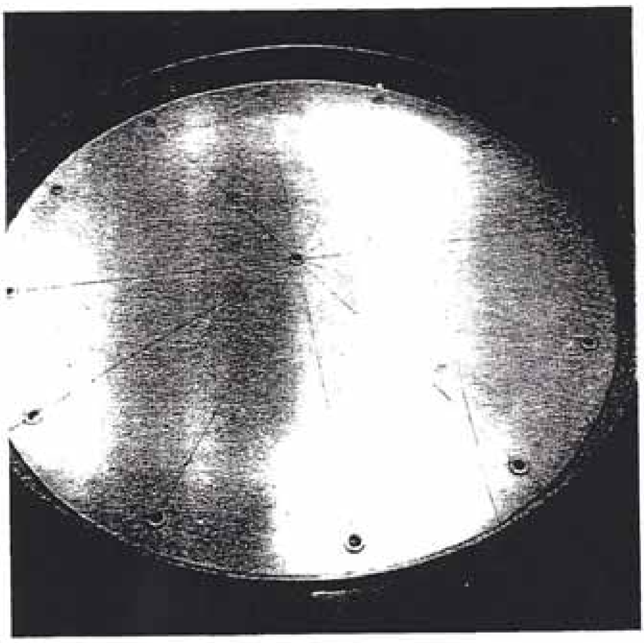
Welding:
Jars and other receptacles for cream, etc., shafts for electric toothbrushes, toothbrush cases, tube tops and caps, cases and other packagings for cosmetic articles, protective foil on cosmetic articles, lids, blow-moulded receptacles with injection moulded spouts, yoghurt cartons and lids, ampules for blood transfusion equipment, artificial kidneys, filters for biological applications, screw-tops on flexible containers.

Flanging:
Make-up mirrors, ampule plugs.

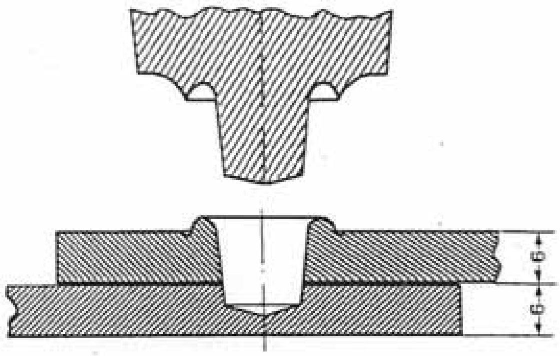
12.10 Others

Sewing:
Hemming of fabrics, sewing of stretch fabrics, pleating of quilts made of synthetic non-woven materials.

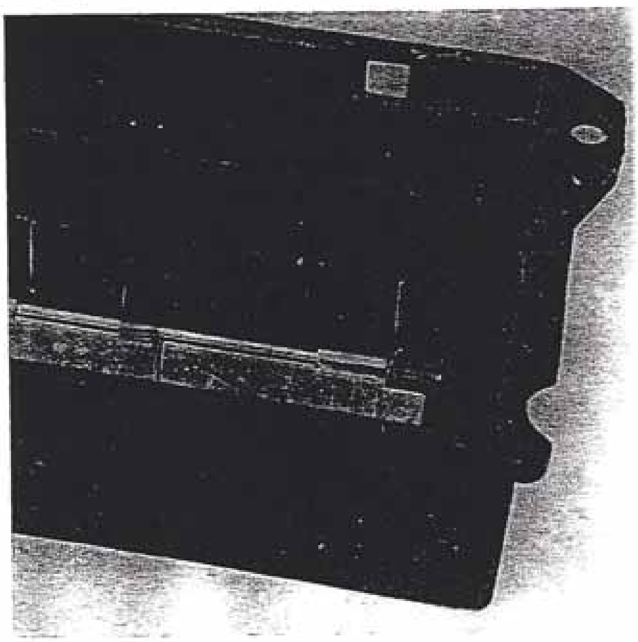
13. Collection of examples



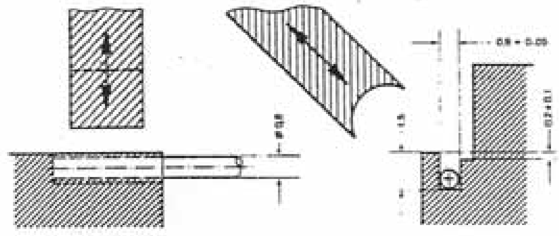
Plant pot



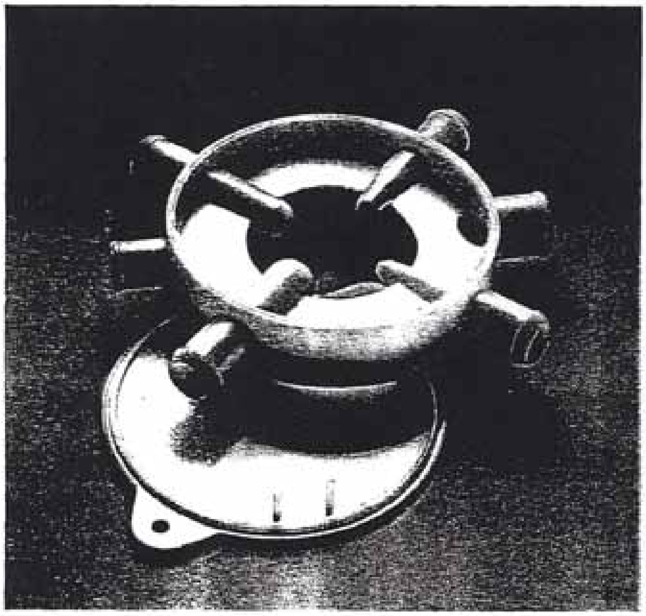
The level extruded base made of ABS is joined without edge preparation by means of ultrasonic spot welding to the thermoformed receptacle.



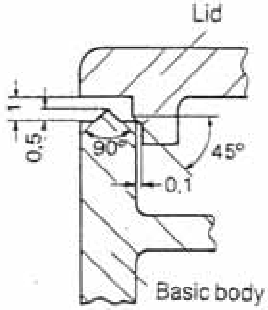
Flap for car radio:



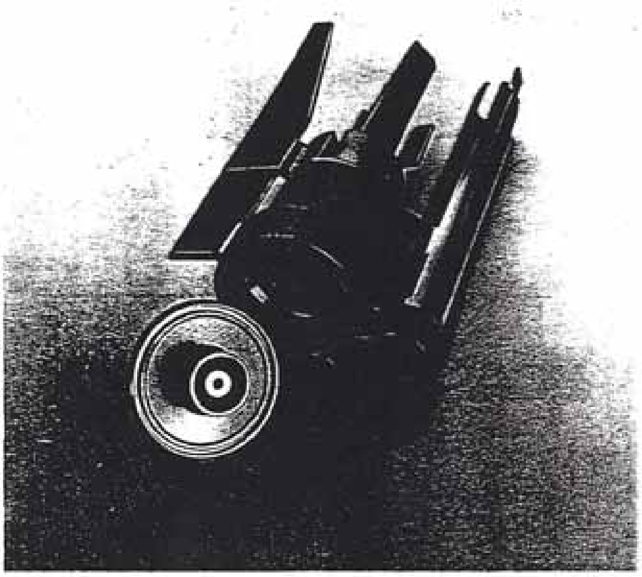
The steel axle is fixed ultrasonically at both ends in the housing made of ABS. The sonotrode is placed while vibrating.



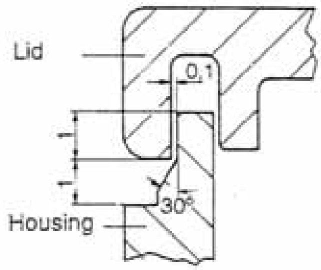
Reflux preventer



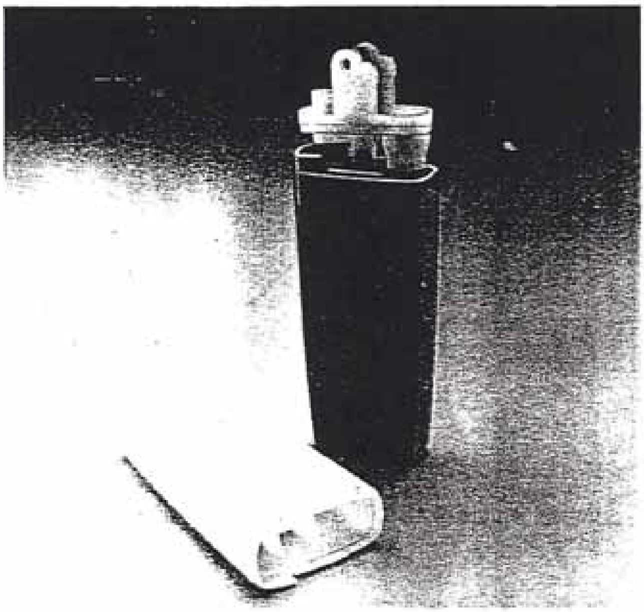
The reflux preventer made of POM prevents (dirty) water from a domestic appliance (e.g. dishwasher) from flowing back into the supply pipe in the possible event of low pressure. The reflux preventer consists of a basic body and two lids, which are welded with each other so as to be liquid-tight.



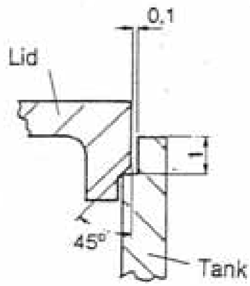
Time control for a toaster



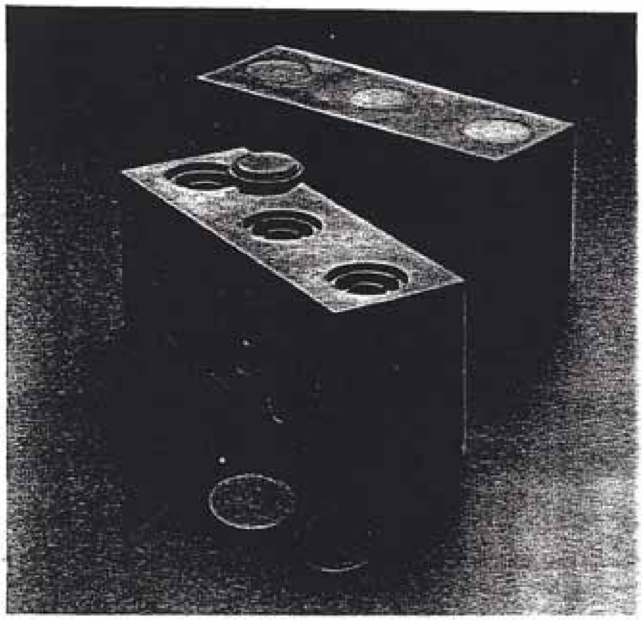
This time control enables the duration of the toasting to be set according to individual requirements, so as to be accurate and repeatable. The housing and the lid are injection moulded with POM. The lid is welded with the housing so as to be air-tight.



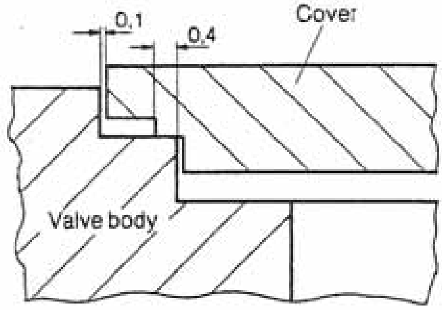
One-way cigarette lighter



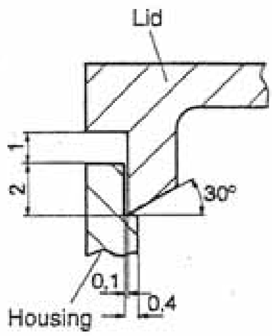
The components, which are subject to internal pressure, consist of the tank and a lid which is welded with it. They are made of POM.



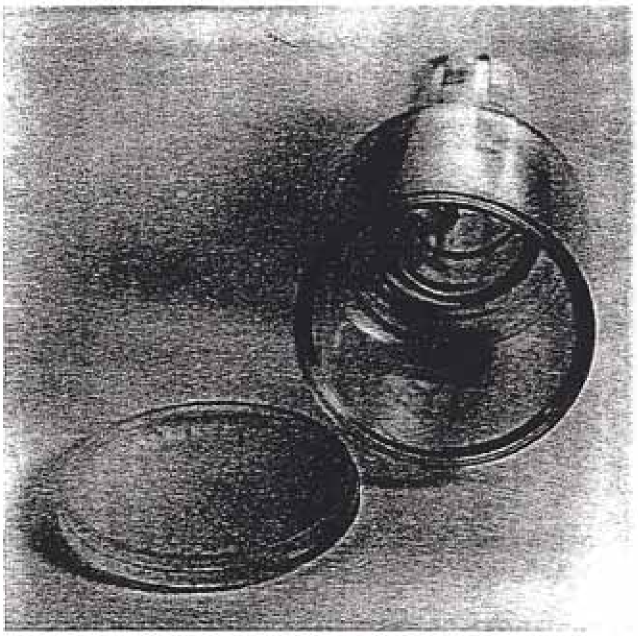
Pneumatic unit



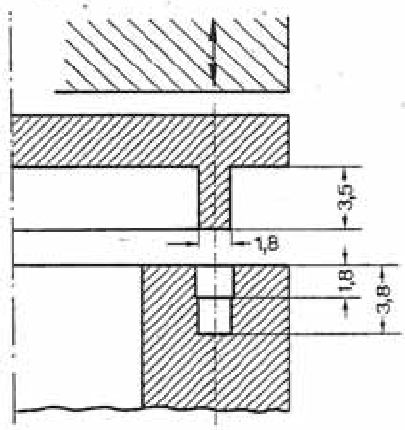
Pneumatic units made of POM are used for controlling pressure, quantity and direction. In each valve body there are several valve pistons, which move in a cylindrical drilled hole. After assembly the drilled holes are sealed with disc-shaped covers in an ultrasonic welding process.



Controls which are injection moulded with POM are used in single lever mixing valves. After the incorporation of ceramic sealing washers the lid and the housing are welded with each other so as to be liquid-tight.

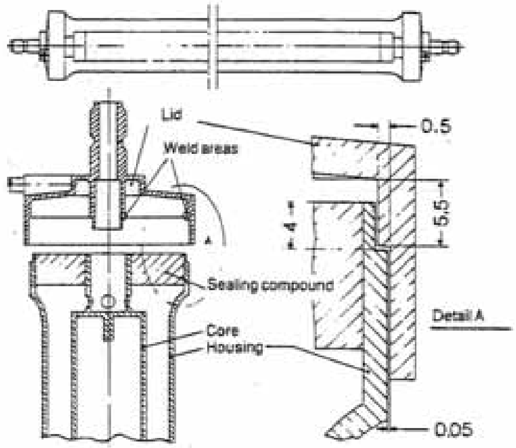


Quenching chamber

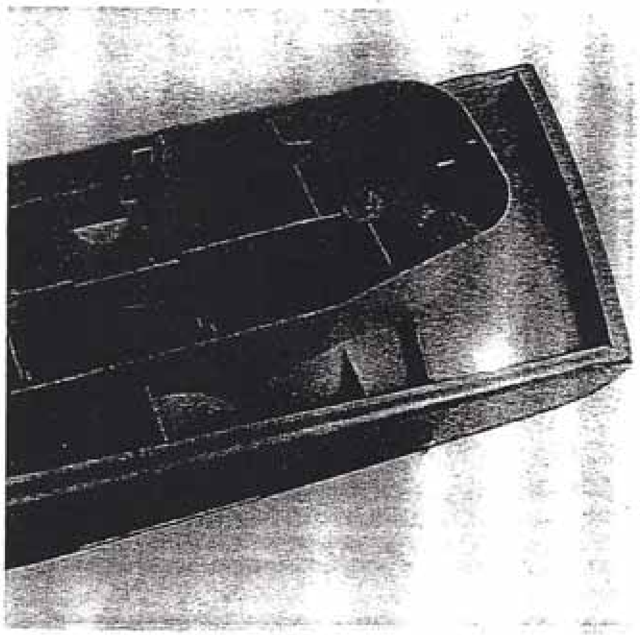


The quenching chamber made of PA11 is welded with a double flattened seam on account of the required pressure tightness. The test pressure is 10 bar.

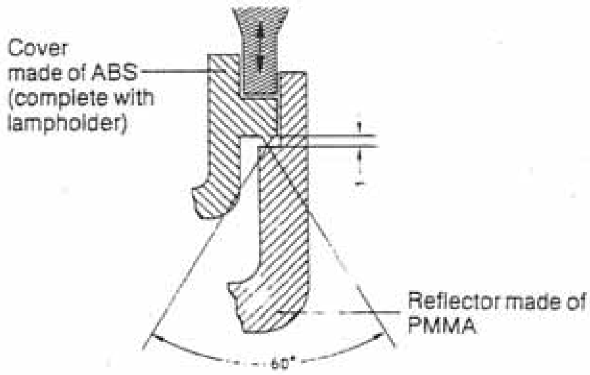
Artificial kidney (Dialyse)



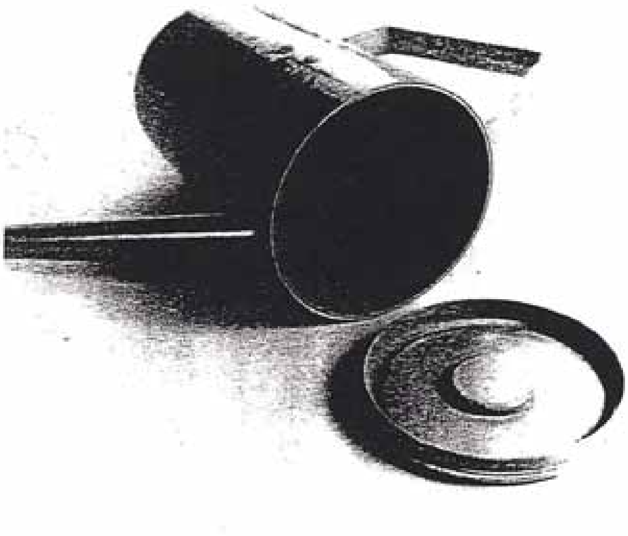
The housing, the core and the lid are welded in one cycle. All welded parts are made of PC.



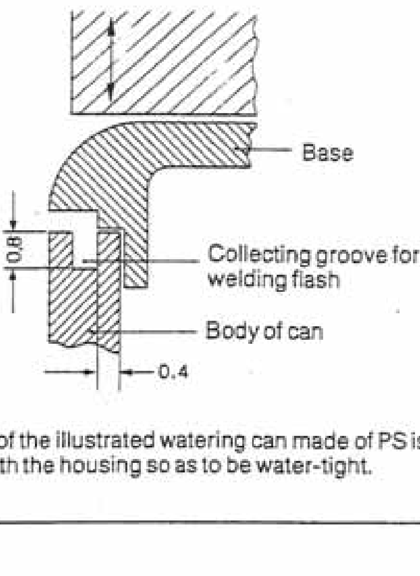
Rear lamps for motor vehicles



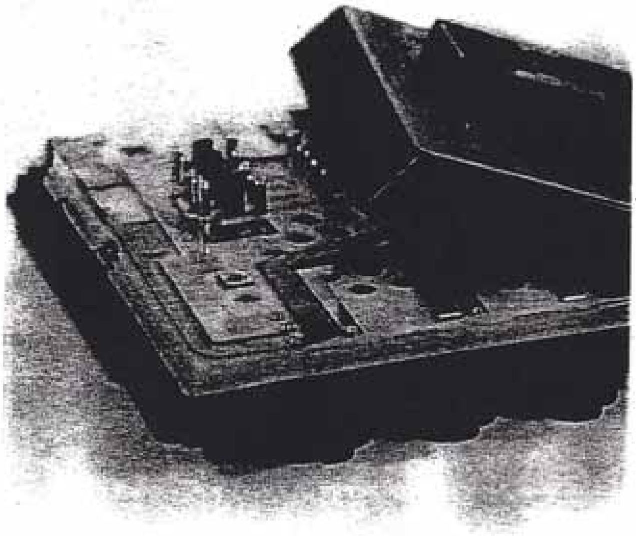
For the rear lamp shown here a cover made of ABS is welded in one process with the reflector housing made of PMMA.



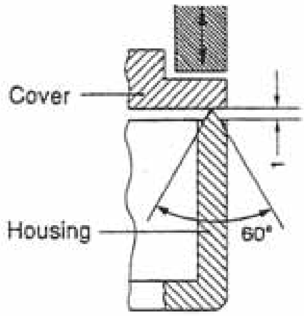
Watering can



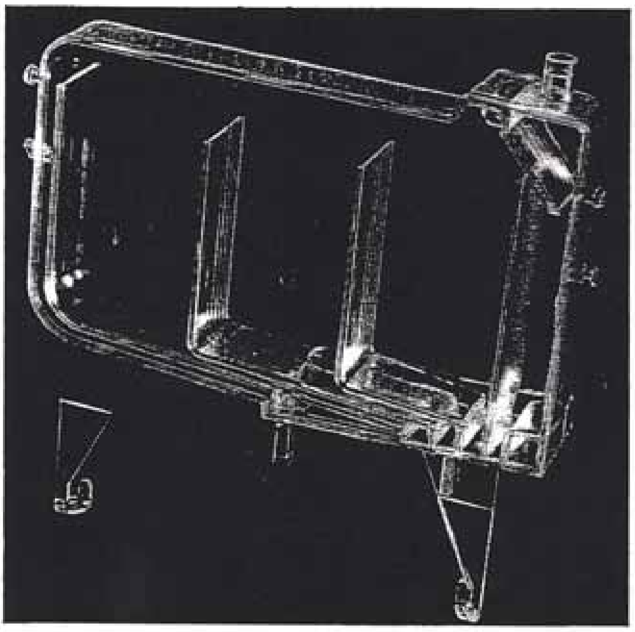
The base of the illustrated watering can made of PS is welded with the housing so as to be water-tight.



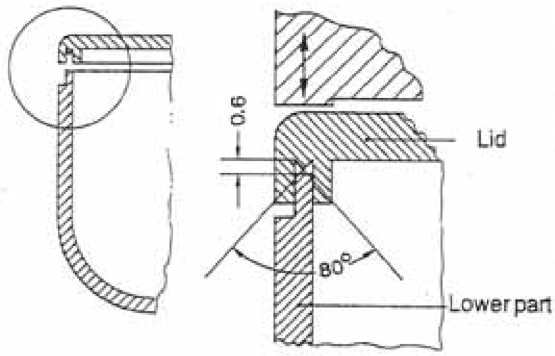
Central electrical system for motor vehicle



The housing is welded tight with the lid, both being made of GF_{30}-PA66. For reasons relating to the parts it was necessary to weld with a wedge-shaped energy director. A shear joint would be better.

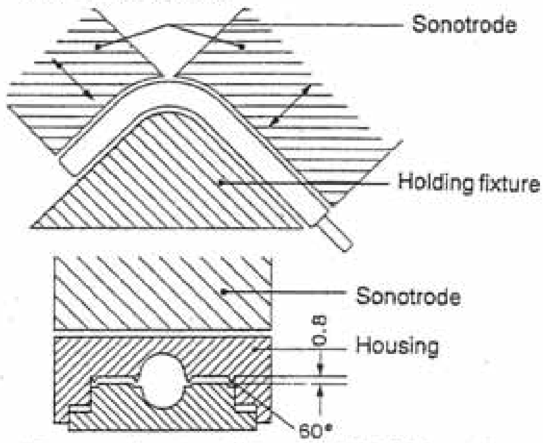


Graduated beaker for urine



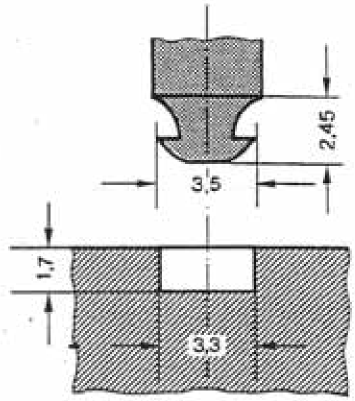
The lid with the lower part and all the inside bars are welded so as to be water-tight. All the welded parts are made of SAN.

Curved water outles

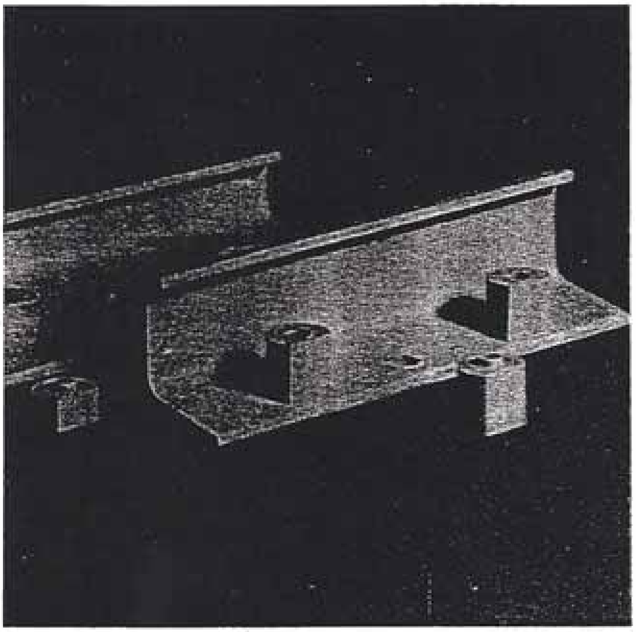


The curved water outlet made of GP-PPO modified has to be welded so as to be absolutely water-tight and mechanically stable (filler arm of the mouth rinse beaker next to the dentist's chair).

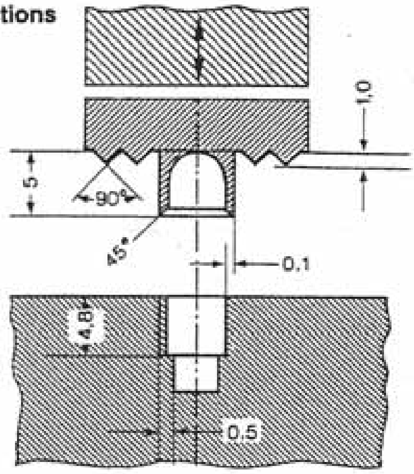
Spectacle frames



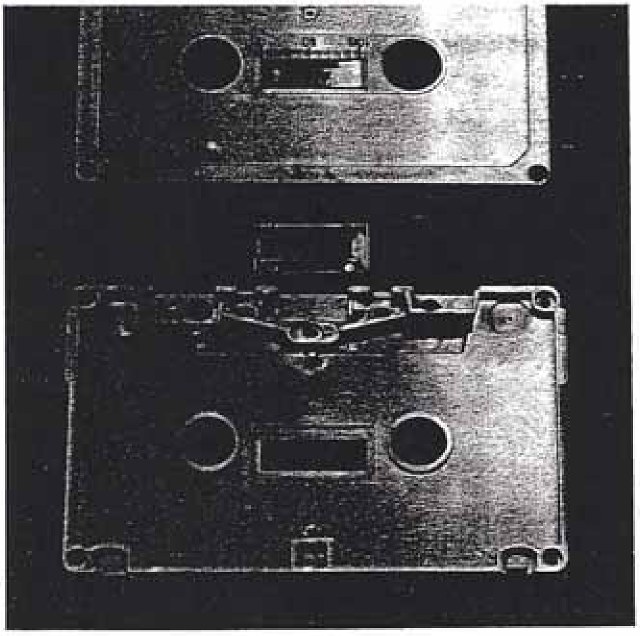
The hinges made of chrome steel are embedded in spectacle frames made of PA6. The extraction force is up to 700N.



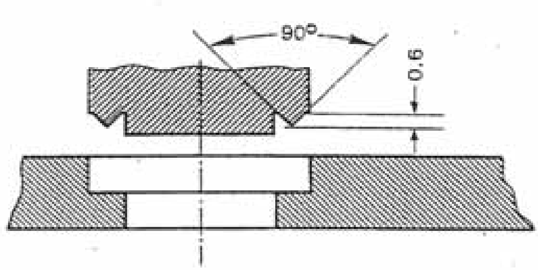
Angle sections



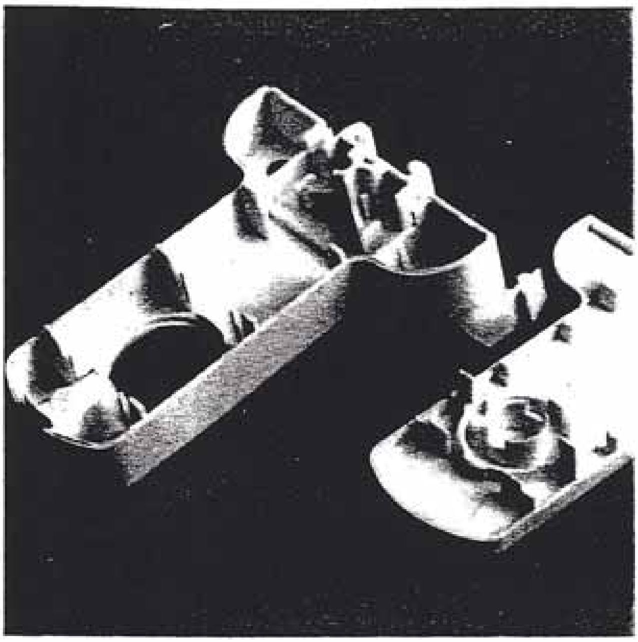
The injection moulded spacing bolts are welded with the extruded angle section. Both parts consist of ABS.



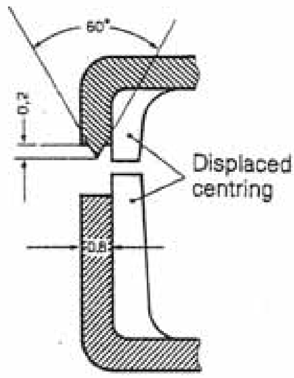
Compact cassettes



The viewing window made of N-PS is welded tight with the housing made of impact-proof PS.

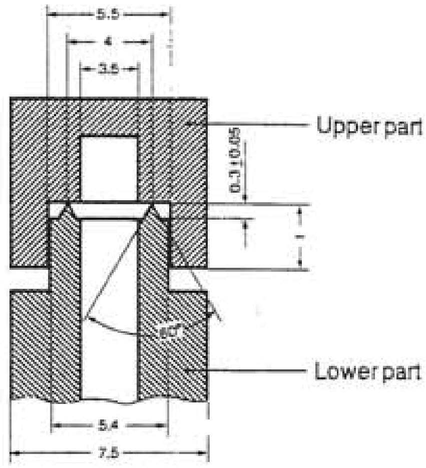


Mounting for fluorescent tubes

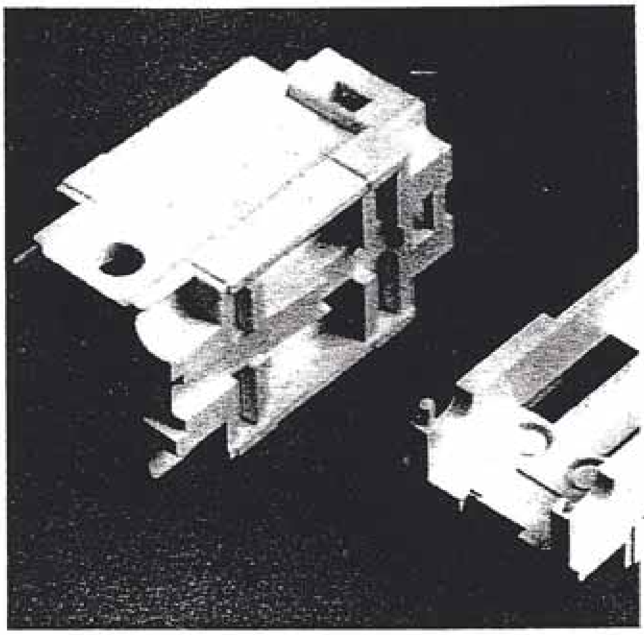


The centring of the two thin-walled parts made of PC is done by means of laterally displaced centring studs. As a result of interrupting the energy directors shorter welding times are obtained with a lower machine power output. A tight weld is not necessary.

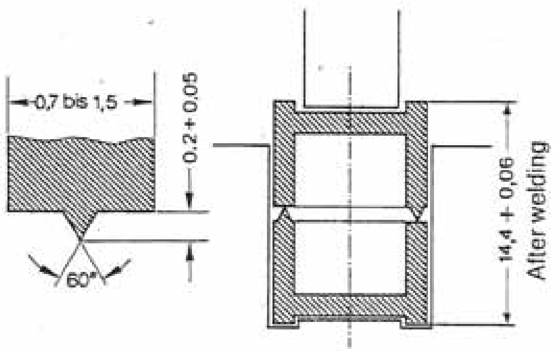
Pushbutton



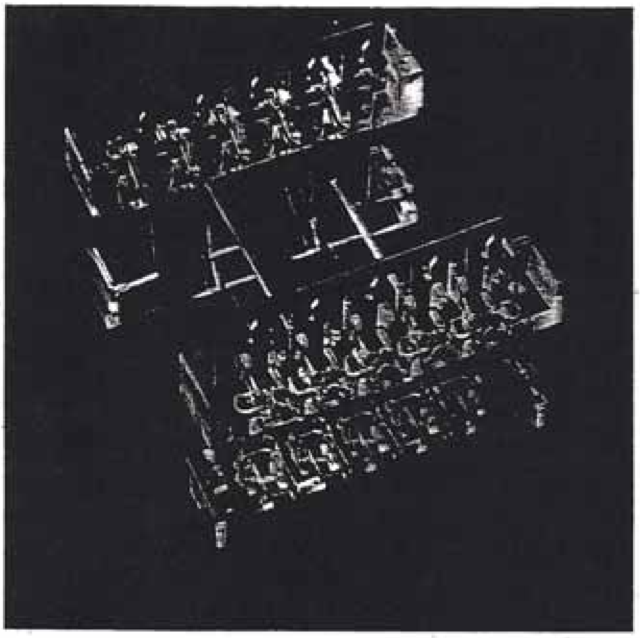
The upper part made of PC is welded with the lower part made of GF_{20}-PC.



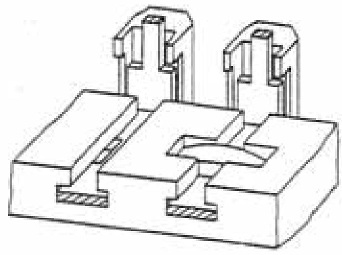
Pushbutton body



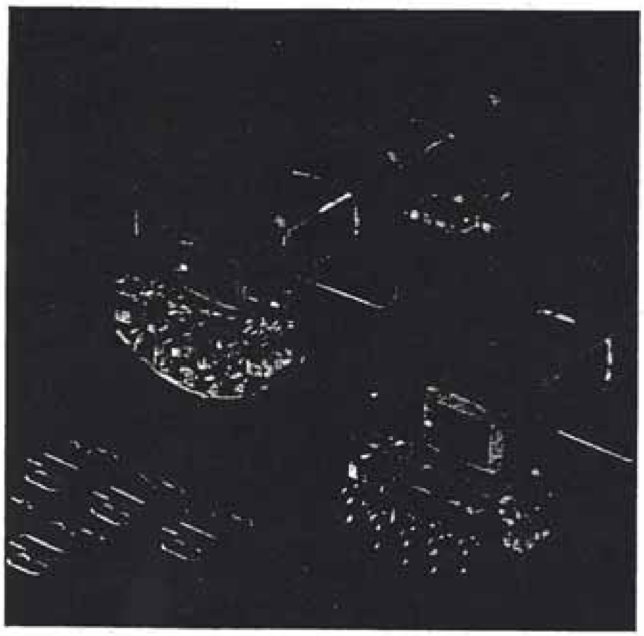
The component tolerances can be adjusted by means of the path dependent switching off of the ultrasound. Both welded parts are made of PC.



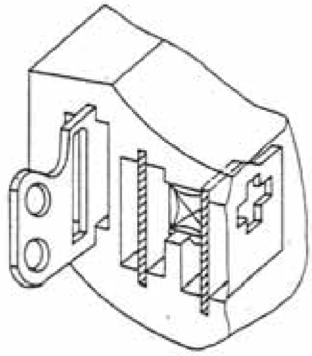
Repeating coils



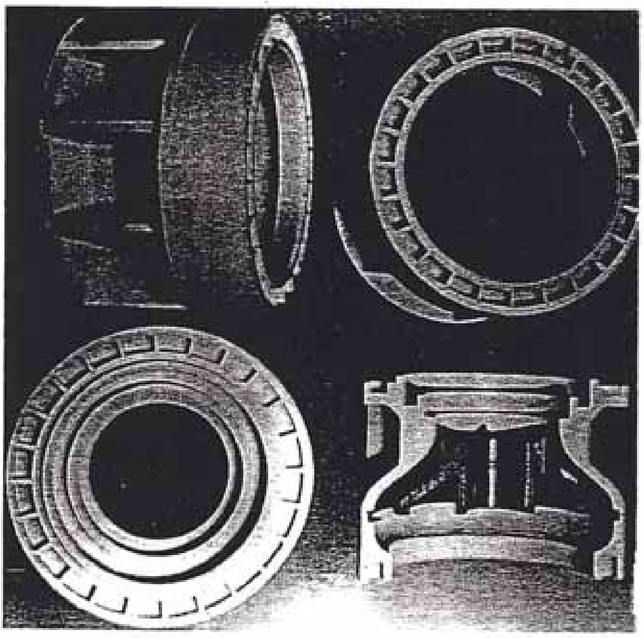
Ultrasound is used to fix in one cycle the soldering tags in the coil housing made of PC.



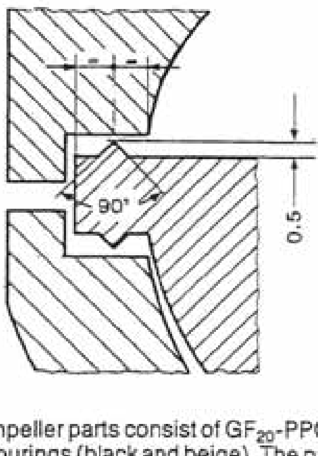
Induction coils



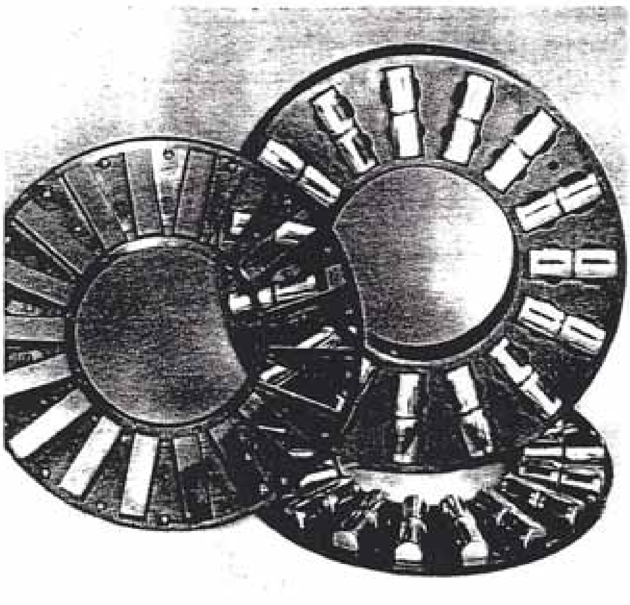
Ultrasound is used to fix in one process five soldering tags in the coil housing made of PC.



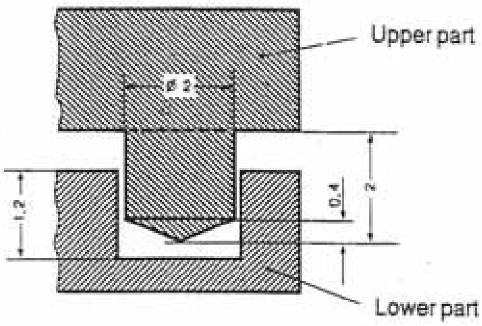
Pump impeller



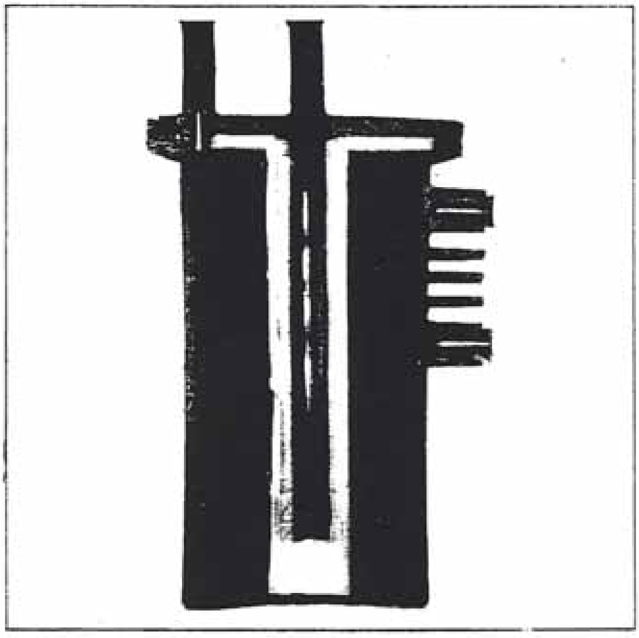
The pump impeller parts consist of GF_{20}-PPO with different colourings (black and beige). The particular feature of this weld is that three components are welded in one process.



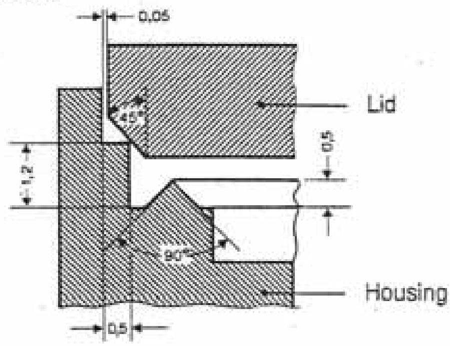
Thrust bearing



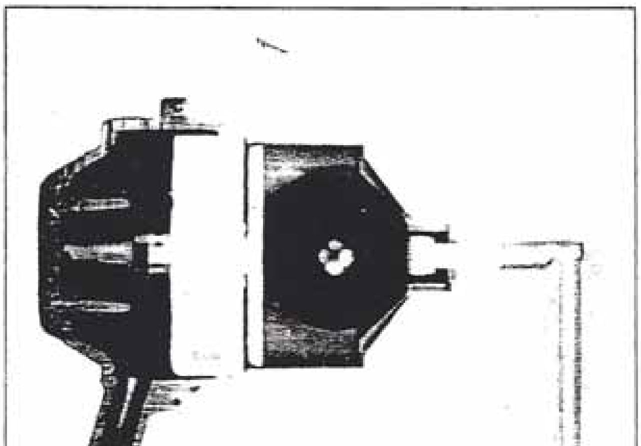
The two halves of the cage are injected with GF_{30}-PA66. After the rollers have been fitted in the lower part of the cage, the upper part is brought down, fitted over the injected journals and welded ultrasonically.



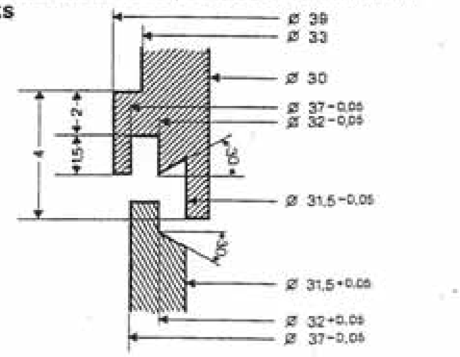
Petrol filter



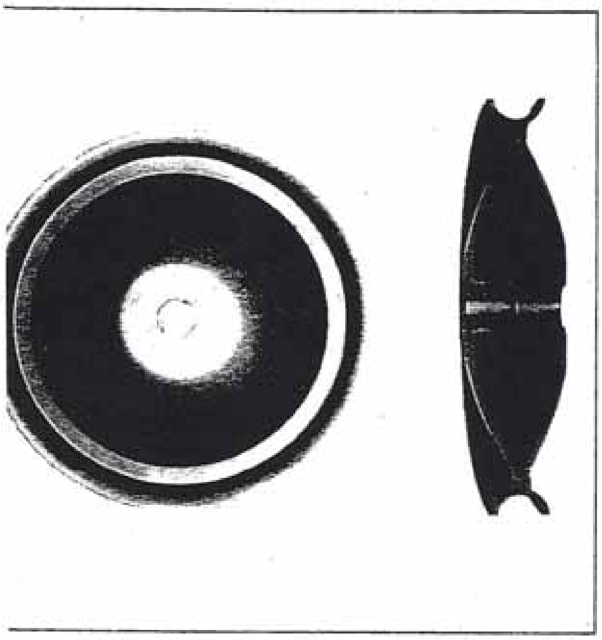
The filter housing and the lid are made of GF_{30}-PA66. The filter insert made of PE is clamped to the housing at the same time as the lid is welded. Special requirements in relation to the weld: operating pressure-tightness up to 5 bar, test pressure 8 bar, bursting pressure minimum 11 bar.



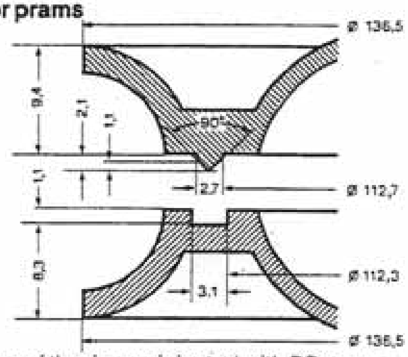
Ventilation and air-escape valve for motor vehicle tanks



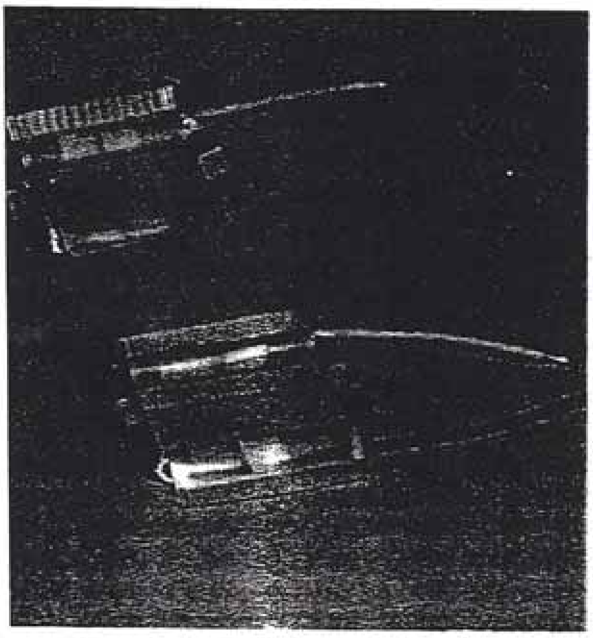
The two outer parts are injected with POM and are welded ultrasonically in the far field without a sonotrode casting. To obtain absolute pressure-tightness the weld was made as a concealed flattened weld. Special requirements: operating pressure up to 6 bar, test pressure 10 bar, bursting pressure minimum 30 bar.



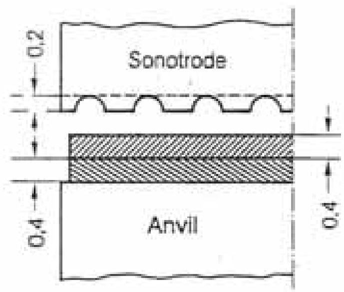
Wheel rims for prams



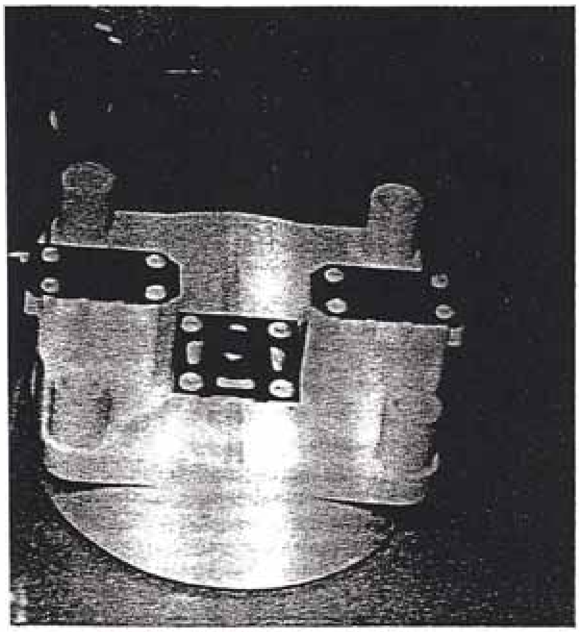
The two halves of the rim are injected with PS so as to have a high impact strength. The welding takes places in the outer ring, the two parts being fixed to each other simultaneously during welding as a result of the special design of the weld seam. Considerable demands are made on the weld, as pram wheels are tested for shock resistance and torsion by the Technischer Uberwachungsverein (German government body responsible for motor vehicle safety standards).



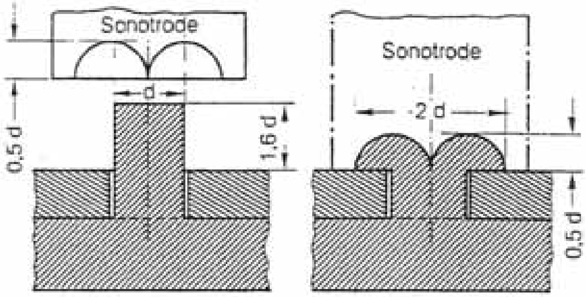
Field coil for electric motor



The wound field coils are insulated with PE foil (groove insulation). It is necessary here to weld the two ends of the foil flat ultrasonically. The sketch shows the design of the sonotrode.



Cover for electric motor



Two brushholders and a sintered bearing are riveted ultrasonically onto the cover made of PA.