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SURFACE VEHICLE INFORMATION REPORT

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Submitted for recognition as an American National Standard

AUTOMOTIVE METALLURGICAL JOINING

Foreword—This Document has also changed to comply with the new SAE Technical Standards Board format.

1. Scope—This report is an abbreviated summary of metallurgical joining by welding, brazing, and soldering. It is generally intended to reflect current usage in the automotive industry; however, it does include some of the more recently developed processes. More comprehensive coverage of materials, processing details, and equipment required may be found in the Welding Handbook, Soldering Manual, and other publications of the American Welding Society and the American Society for Testing and Materials. AWS Automotive Welding Committee publications on Recommended Practices are particularly recommended for the design or product engineer.

This report is not intended to cover mechanical joining such as rivets or screw fasteners, or chemical joining processes such as adhesive joining.

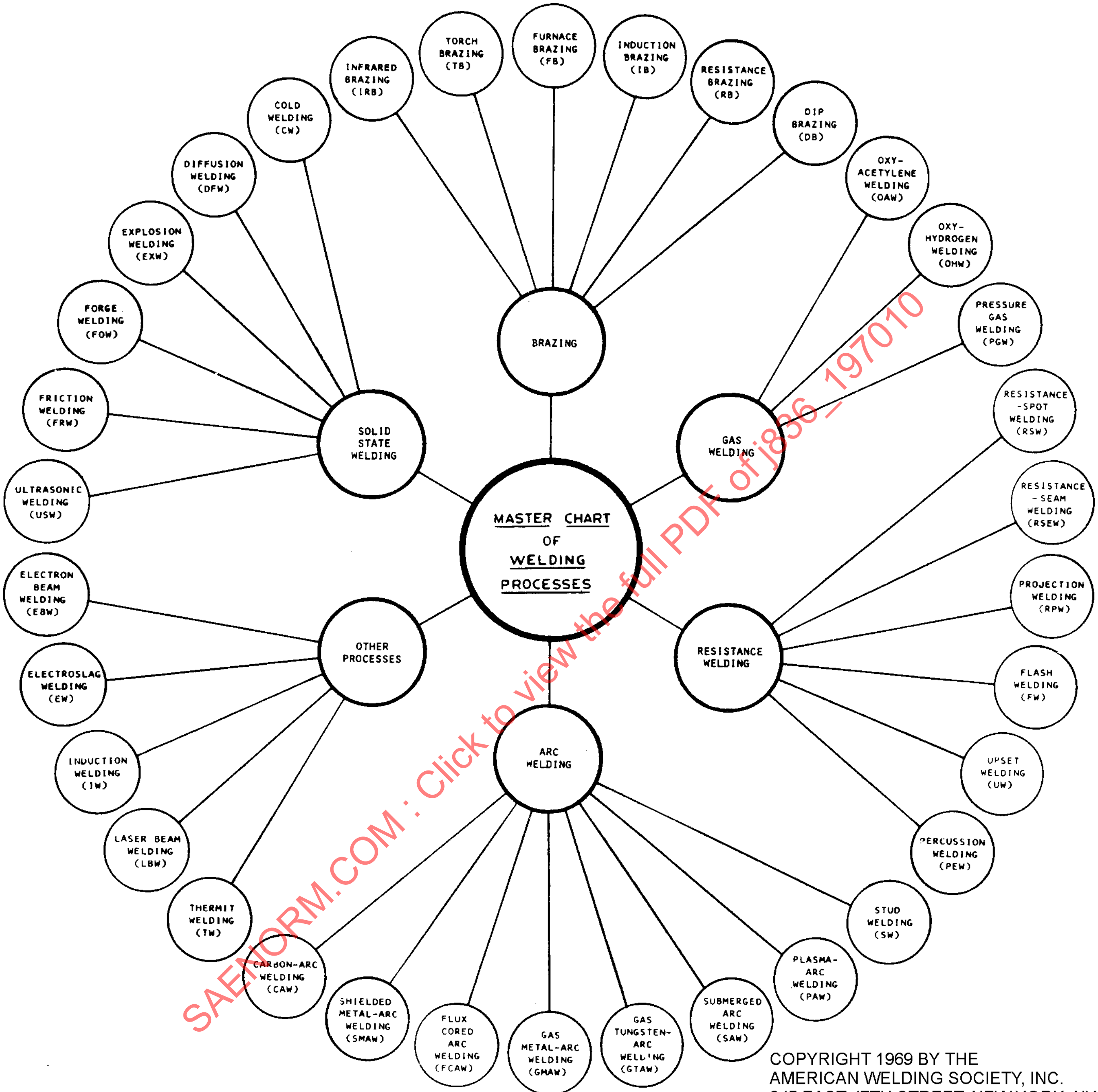
1.1 Classification of Welding Processes—Current welding practices utilize a great variety of other welding processes not covered in the scope of this report. The AWS has classified all these processes in their Master Chart of Welding Processes (Figure 1).

1.2 Standard Welding Symbols

1.2.1 With the advancement of welding technology, more welding variables and controls are being continuously added to the manufacturing requirements of weldments. These may include:

1.2.1.1 Dimensional requirements of welds (size, length, pitch, number of welds, etc.).

1.2.1.2 Integrity requirements, such as shear strength for resistance welds, depth of penetration, etc.



AWS A1.1-69

FIGURE 1—AMERICAN WELDING SOCIETY MASTER CHART OF WELDING PROCESSES
(REPRINTED BY PERMISSION OF AMERICAN WELDING SOCIETY)

1.2.1.3 Performance requirements of welds and welded joints. These may include:

1.2.1.3.1 Dimensional requirements (joint preparation, root opening, etc.).

1.2.1.3.2 Process requirements (series, direct, indirect, over and under welding, and process designations).

1.2.1.3.3 Other requirements such as weld all around, field weld, etc.

1.2.2 Symbols provide a universal means of communicating the above referenced information from the product designer to the process man without the risk of misinterpretation. Internationally accepted process and weldment symbols are shown in Figure 2.

1.3 Automotive Welding Applications—Certain welding processes have made further inroads in the area of automotive welding than others. This fact is caused not only by their greater adaptability to perform automotive welds, but also by keeping up with high production requirements at lower costs. At the present time the following processes are being used extensively:

a. Resistance welding processes.
b. Arc welding processes.
c. Brazing and soldering.
d. Special process.

2. References

2.1 Applicable Publications—The following publications form a part of the specification to the extent specified herein. Unless otherwise indicated the lastest revision of SAE publications shall apply.

2.1.1 American Welding Society Publications—Available from??

American Welding Society Welding Handbook, Fifth Edition, Section 2, Chapter 30, p. 30.1.
American Welding Society Welding Handbook, Fifth Edition, Section 5, Chapter 90, p. 90.18.
Resistance Welder Manufacturers Association Manual.
American Welding Society Welding Handbook, Fifth Edition, Section 2, Chapters 30 and 32.
Resistance Welding Manual (RWMA), Third Edition, Chapter 4, p. 52.
American Welding Society Welding Handbook, Fifth Edition, Section 2, Chapter 30.
Recommended Practices for Automotive Welding Design D8.4-61.
American Welding Society Welding Handbook, Fifth Edition, Section 2, Chapter 31.
Resistance Welding Manual (RWMA), Third Edition, Chapter 5, p. 67.
American Welding Society Welding Handbook, Fifth Edition, Section 2, Chapter 31.
Resistance Welding Manual (RWMA), Third Edition, Chapter 5, p. 67.
American Welding Society Welding Handbook, Fifth Edition, Chapter 31.
Resistance Welding Manual (RWMA), Chapter 9, p. 111.
American Welding Society Welding Handbook, Fifth Edition, Section 2, Chapter 35 (1964).
W. C. Rudd, "High Frequency Resistance Welding." Welding Journal, Vol. 36, July 1957, pp. 703–707.
"Modern Joining Processes," Chapter 5, p. 51. American Welding Society (1966).
American Welding Society Welding Handbook, Fifth Edition, Section 2, Chapter 25.
American Welding Society Welding Handbook, Fifth Edition, Section 2, Chapter 28.
American Welding Society Welding Handbook, Fifth Edition, Section 2, Chapter 27.
American Welding Society Recommended Practices for Automotive Welding Design D8.4-61.
American Welding Society Welding Handbook, Fifth Edition, Section 2, Chapter 29.
American Welding Society Welding Handbook, Fifth Edition, Section 3, Chapter 54.
American Welding Society Welding Handbook, Fifth Edition, Section 3, Chapter 52.
American Welding Society Welding Handbook, Fifth Edition, Section 3, Chapter 56.
American Welding Society Welding Handbook, Fifth Edition, Section 3, Chapter 49.
American Welding Society Soldering Manual, First Edition, 1959.

2.1.2 SAE Publication—Available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096-0001.

Solders—SAE J473, Table 1.

2.1.3 ASTM Publication—Available from ASTM, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959.

ASTM solder classifications are given in Tables 44.3 and 44.4 of the Welding Handbook, American Welding Society, Fifth Edition, Section 3.

3. Resistance Welding Processes—Resistance welding is a group of welding processes wherein coalescence is produced by the heat obtained from resistance of the work to the flow of electric current in a circuit of which the work is a part and by the application of pressure. It differs somewhat from other forms of welding in that no extraneous materials, such as filler rods, fluxes, etc., are utilized; thus the metallography of the weld is not complicated by the addition of materials and the cost of consumable material is nonexistent.

The Master Chart of Welding Processes classifies six basic resistance welding processes; however, the great majority of metal joining is accomplished by the first three of the listed processes. These processes are:

1. Resistance-spot welding.
2. Resistance-seam and roll spot welding.
3. Projection welding.
4. Flash welding.
5. Upset welding.
6. Percussion welding.

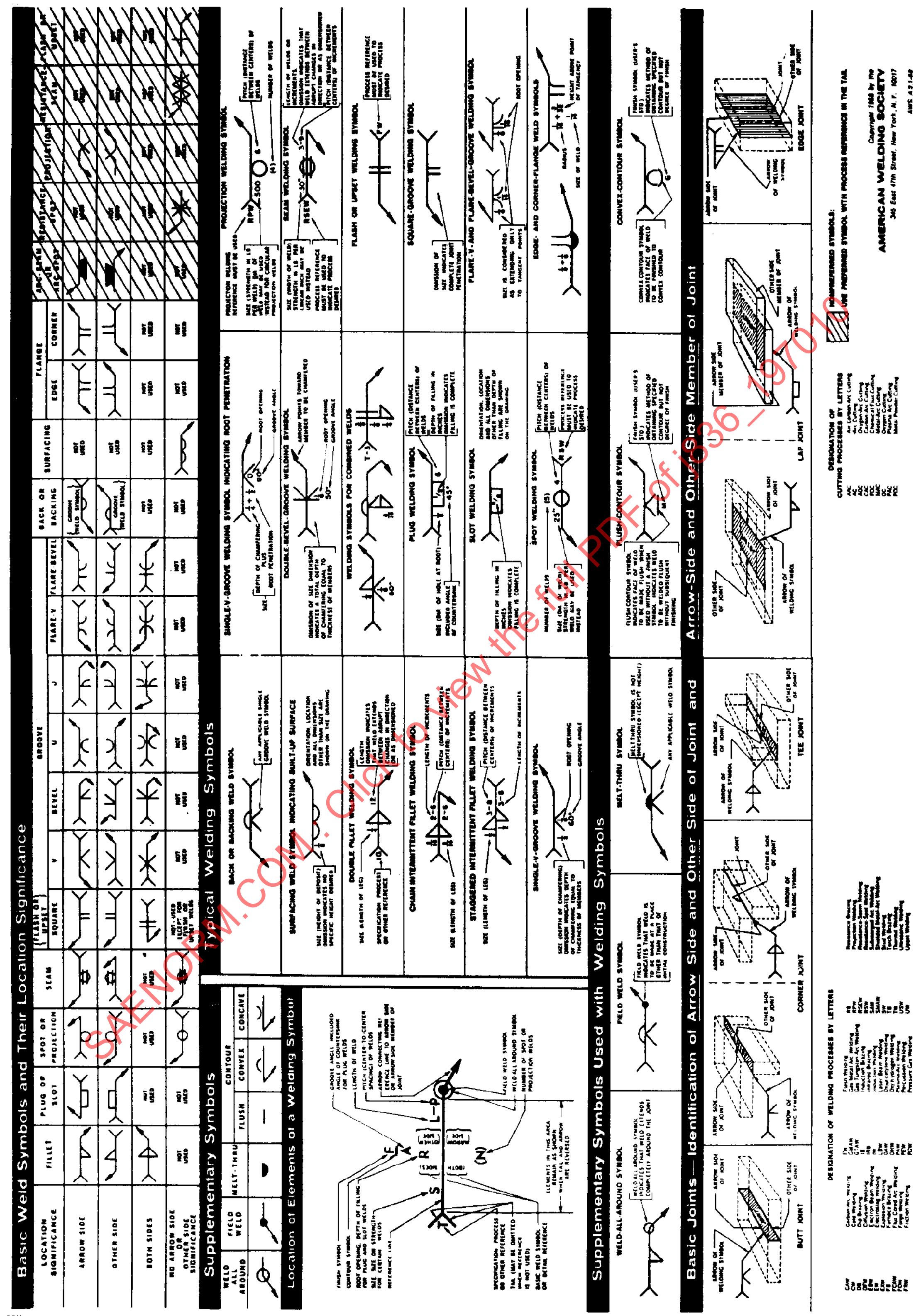


FIGURE 2—AMERICAN WELDING SOCIETY STANDARD WELDING SYMBOLS
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Each of the processes described develops the heat of fusion by the resistance offered to short time flow of low-voltage, high-density electric current. Force is always applied before, during, and after the application of current to assure a continuous electrical circuit and to forge the heated parts together.

3.1 Resistance-Spot Welding—Resistance-spot welding is a process wherein coalescence at the faying surfaces is produced in one spot by the heat obtained from the resistance to the flow of electric current through the work parts held together under pressure by electrodes. The size and shape of the individually formed welds are limited primarily by the size and contour of the electrodes (see Figure 3).

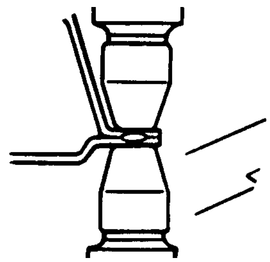


FIGURE 3—RESISTANCE-SPOT WELD

In the majority of the commercial resistance-spot welding applications, the alternating current single-phase system is used. It is the least expensive and simplest form of resistance welding equipment comprised of:

1. Welding transformer.
2. Force applying system - air, hydraulic, or spring type.
3. Timer and contactor.
4. Associated cables and hoses.

Figure 4 shows the resistance-spot weld setup.

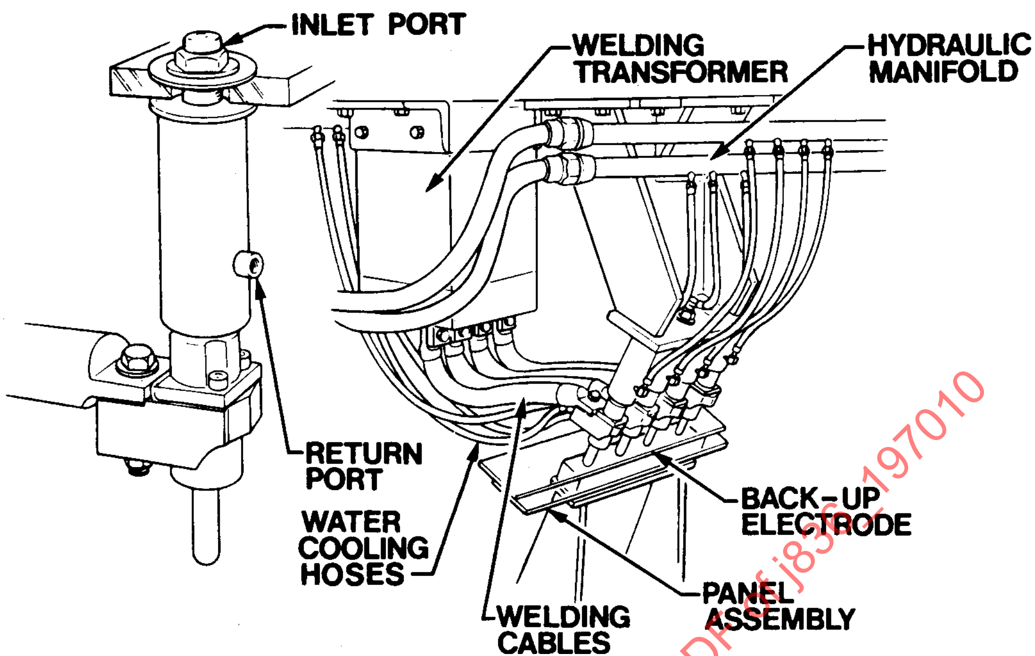


FIGURE 4—RESISTANCE-SPOT WELD SETUP

Resistance welding equipment varies in form from a portable resistance-spot welding gun, which makes a single spot at a time and is taken to the work, to a multiple spot welding machine which will make as many as 50 or more spot welds simultaneously on assemblies shuttled in and out of the machine at rates as high as 600/h. See Figure 5–Figure 7 for the respective types of equipment.

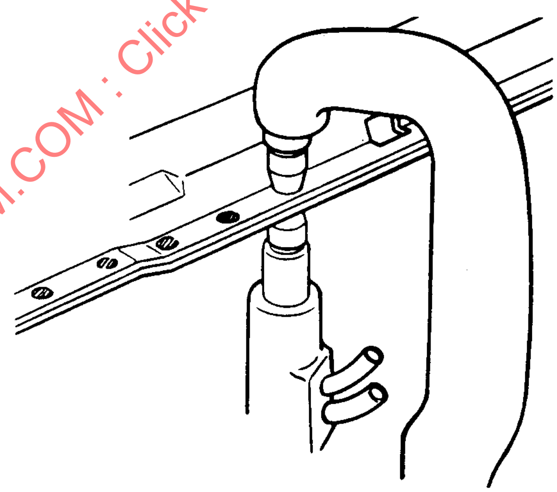


FIGURE 5—PORTABLE RESISTANCE WELD GUN

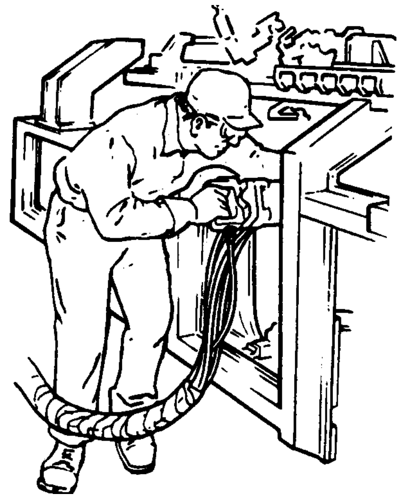


FIGURE 6—PORTABLE RESISTANCE-SPOT WELDING GUN APPLICATION

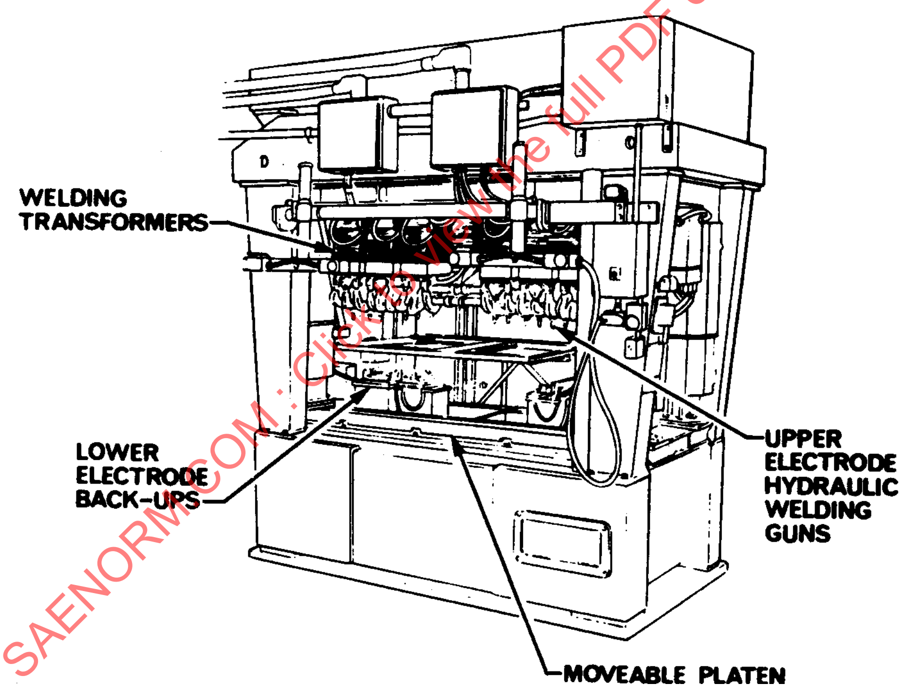


FIGURE 7—MULTIPLE ELECTRODE PRESS WELDING MACHINE

The complexity of the spot welding equipment is predicated by the volume of production to support the equipment investment. The initial equipment cost is high compared to manual arc and gas equipment; however, the rate of welding is faster and the consumable material cost is nonexistent.

High-quality fabrications can be produced consistently by use of proper designs and welding procedure. During the design of the product to be assembled by resistance-spot welding, consideration must be given to provide adequate flange widths and accessibility for welding equipment application. Difficulty in positioning and applying the welding equipment can materially affect production rate and quality.

3.1.1 REFERENCES

3.1.1.1 American Welding Society Welding Handbook, Fifth Edition, Section 2, Chapter 30, p. 30.1.

3.1.1.2 American Welding Society Welding Handbook, Fifth Edition, Section 5, Chapter 90, p. 90.18.

3.1.1.3 Resistance Welder Manufacturers Association Manual.

3.2 Roll-Resistance Spot Welding—Roll-spot welding consists of making a series of separated spot welds in a row by means of one or two rotating, circular electrodes without retracting the electrodes or removing the welding force between spots. The principles described for conventional spot welding apply also to this process. The weld spacing is obtained and accurately maintained by proper adjustment of electrode speed and current off-time using conventional seam welding equipment. In the case of roll-resistance spot welding utilizing continuous motion, welding times are usually held to lower levels than that used for conventional spot welding, thus requiring higher magnitudes of current. Due to the continuous electrode travel the welds tend to be of an elongated nugget.

Roll-spot welding is usually accomplished on thicknesses up to 1/8 in with continuous motion of the wheel electrodes driven at a constant speed. For heavier thicknesses of 3/16 in and above, an intermittent motion is suggested. In this method, the work stops during the time required to make each individual weld and is automatically advanced the proper distance for the next weldment. This sequence is continued for the full length of the joint.

3.3 Resistance-Seam Welding—Seam welding is a resistance welding process wherein coalescence is produced by the heat obtained from resistance to the flow of electric current through the work parts held together under pressure by circular electrodes. The resultant weld is a series of overlapping spot welds made progressively along a joint by rotating the electrodes.

Seam welding is usually applied to two types of joint designs - lap and flanged-lap. Variations of the standard seam weld principle are mash seam weld, foil-butt seam weld, and butt seam weld. For the respective characteristics of each variety, see Section 3.3.1.

Roll-spot welding is used where precise spacing between welds is desired, as in welding the roof panel at the gutter area on an automobile body. Seam welding to produce a liquid and gas tight joint is used to fabricate automobile gas tanks, buckets, mufflers, water tanks, thin wall piping, etc. Mash seam welding and foil-butt seam welds are used where surface finishing is required after the joining process as there is a minimum of material required to be removed - applied to refrigerator and appliance cabinets and limited automotive outer panel fabrications. The butt seam weld is used for non-structural type joints, examples of which are found in toy and automobile horn fabrication.

Figures 8 and 9 show equipment concepts of a standard seam welder and a schematic of a roll-spot welder, respectively.

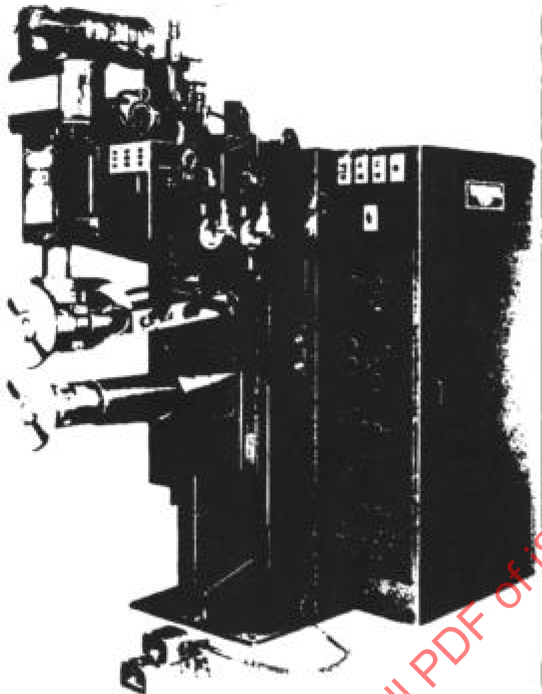


FIGURE 8—RESISTANCE SEAM WELDING MACHINE

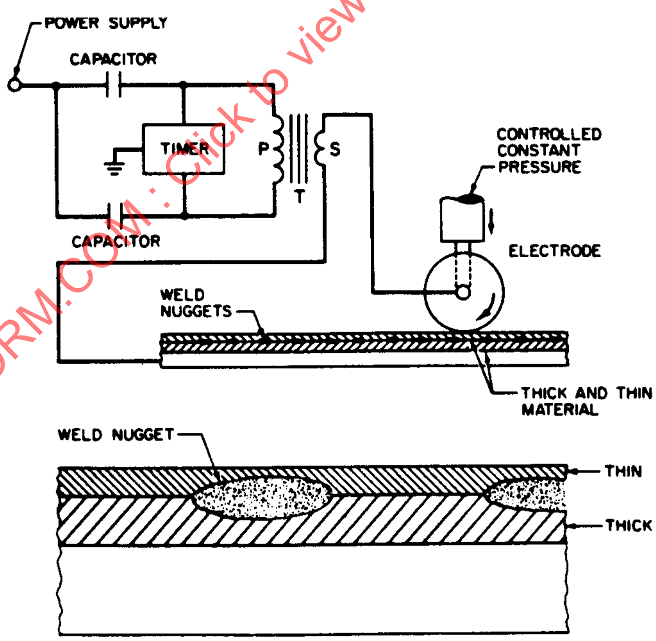


FIGURE 9—ROLL RESISTANCE-SPOT WELDING MACHINE

3.3.1 Additional information can be found on seam-resistance and roll-resistance spot welding and the variation of the process in the following references:

3.3.1.1 American Welding Society Welding Handbook, Fifth Edition, Section 2, Chapters 30 and 32.

3.3.1.2 Resistance Welding Manual (RWMA), Third Edition, Chapter 4, p. 52.

3.4 Projection Welding—Projection welding is a resistance welding process wherein coalescence is produced by the heat obtained from resistance to the flow of electric current through the work parts held together under pressure by electrodes. The resulting welds are localized at predetermined points by the design of the parts to be welded. The localization is usually accomplished by projections, embossments, or intersections.

Projection welding is a modification of the spot welding process. The concentration of the welding current and force is made by projections prepared in the workpiece rather than by the size and shape of the welding electrode. Normally, the projections are formed in the heavier of the two light metal pieces to be joined and in the case of dissimilar metal in the piece with higher electrical conductivity.

Projections can be produced by means of drawing with a punch and die, cold heading, coining, machining, shearing, and using natural projections as is the case with cross wire welding.

Advantages of projection welding which determine where the process can be best applied are:

1. More welds per unit area.
2. Improved surface marring condition.
3. Join difficult metal thickness combinations.
4. Increase output.
5. Less flange width requirement.
6. Consistent location of weld spots.
7. Longer electrode life.
8. Surface conditions less critical.
9. Allows joining components of irregular shapes (weld bolts, nuts, and tapping plates).

There are also factors which can be considered disadvantages:

1. Projections must be provided, which may mean an extra operation.
2. Projection dimensions must be maintained, so die maintenance is required.
3. Electrodes must be maintained although electrode life is longer.
4. Nugget size is limited by projection size.
5. High-capacity equipment required when making multiple simultaneous welds.
6. Limited generally to single-plane welding.
7. Poor condition and unfavorable characteristics of welding machine relative to impact and inertia will adversely affect the weld structural quality.

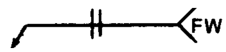
Commercially available hardware items of nuts, bolts, tapping plates, and pads are widely used throughout the industry. Application of other projection welding techniques on sheet metal and wire to sheet metal is limited primarily by the ingenuity of the product designer.

Figures 10–14 illustrate the process and typical applications.

3.4.1 Additional detailed technical information related to the process and product design requirements can be found in the following references:

3.4.1.1 American Welding Society Welding Handbook, Fifth Edition, Section 2, Chapter 30.

3.4.1.2 Recommended Practices for Automotive Welding Design D8.4–61.



3.5 Flash Butt Welding—Flash butt welding is a resistance welding process whereby the weld is made over the entire area of the abutting surfaces, and the upset force is applied only after heating is substantially completed.

The majority of the production machines is completely automatic (Figure 15). Movable platens, which carry the movable workpiece, are cam operated to control travel rate and acceleration. Unlike other resistance welding processes in flash butt welding, the heat is generated by the arc flashing action and only slightly by the actual resistance of the workpieces. Flashing is maintained for a sufficient length of time to develop that heat in the work parts to allow the upsetting force to forge the work together and displace all the slag and oxidized material from the joint's faying surface. This displaced metal is referred to as flash and usually is required to be removed by a grinding or cutting procedure.

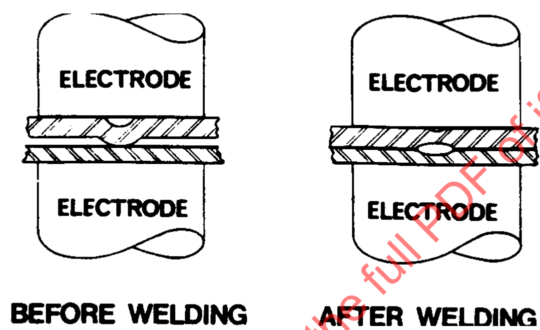
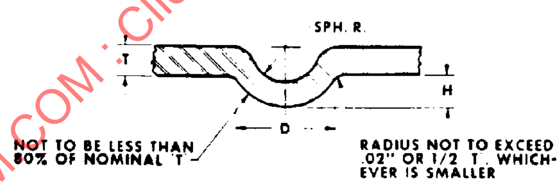


FIGURE 10A—DEFINITION OF PROJECTION WELDING. PROJECTION WELDING IS A METHOD OF RESISTANCE WELDING BY WHICH THE CURRENT FLOW AND HEATING DURING WELDING ARE LOCALIZED AT A PREDETERMINED POINT BY THE DESIGN OF THE PARTS BEING WELDED.



'D' REPRESENTS THE DIAMETER OF THE HOLE IN THE DIE AND THE RADIUS REFERRED TO IS THE ROUNDED EDGE OF THE HOLE

EMBOSSED SHEET THICKNESS	PROJECTION DIAMETER 'D'	THINNER SHEET THICKNESS	PROJECTION HEIGHT 'H'
.030	.105	.030	.030
.035 .041	.120	.035 .041	.035
.047 .054	.135	.047 .054	.040
.059 .067	.150	.059 .067	.045
.075 .089	.170	.075 .089	.050
.105 .120 .125	.190	.105 .120 .125	.055
.194 .209	.250	.194 .209	.070

FIGURE 10B—PROJECTION WELDING EMBOSSMENTS

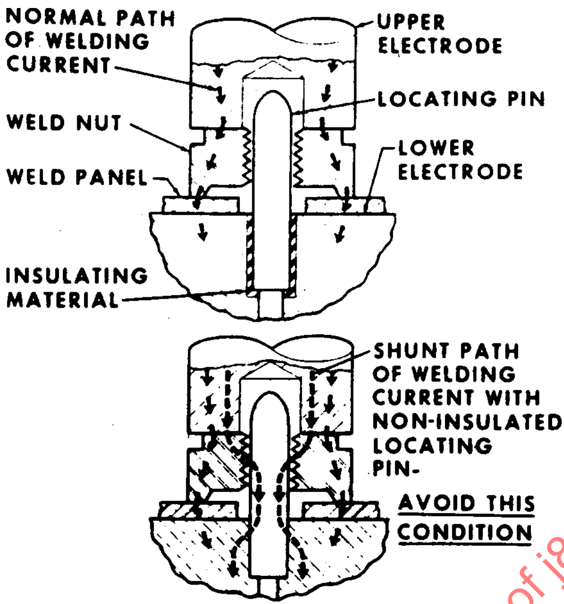


FIGURE 10C—PROJECTION WELD NUT SETUP

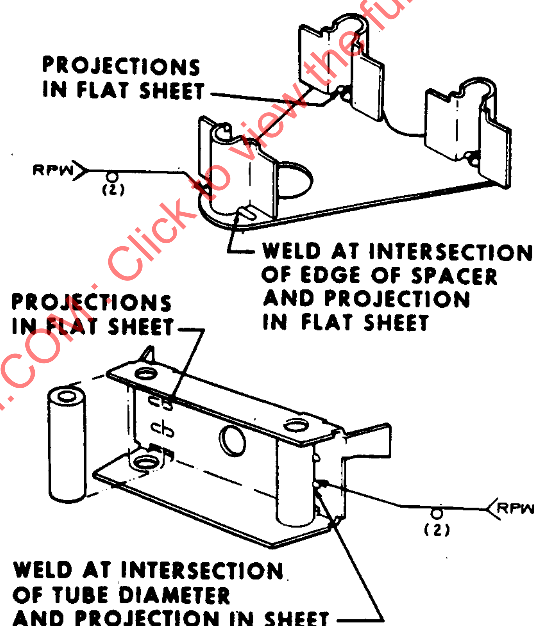


FIGURE 11—TUBES AND IRREGULAR SHAPES

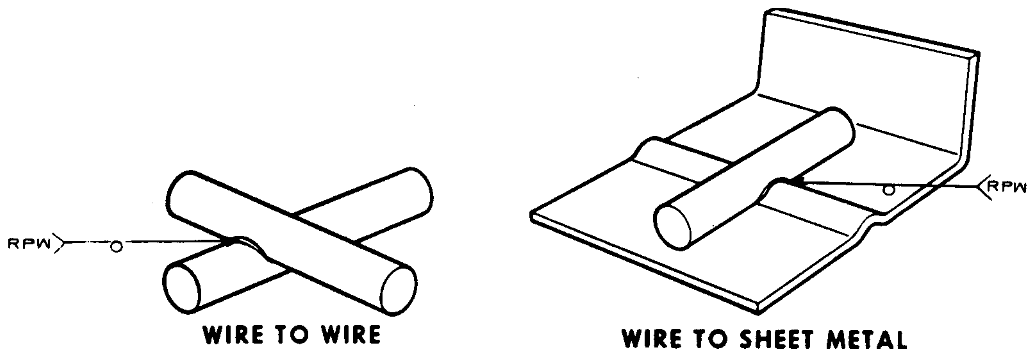


FIGURE 12—CROSS WIRE WELDING

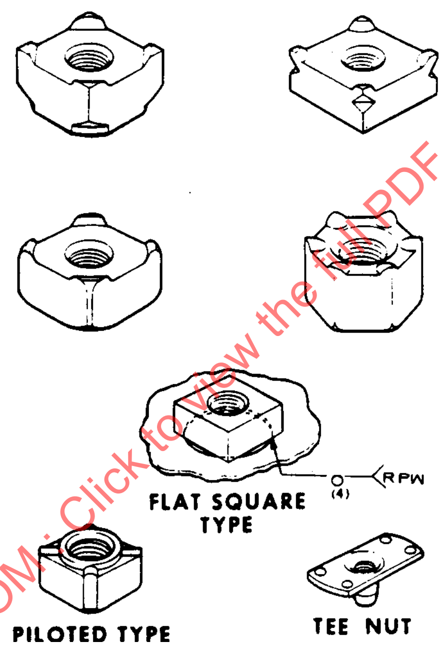


FIGURE 13—PROJECTED WELD

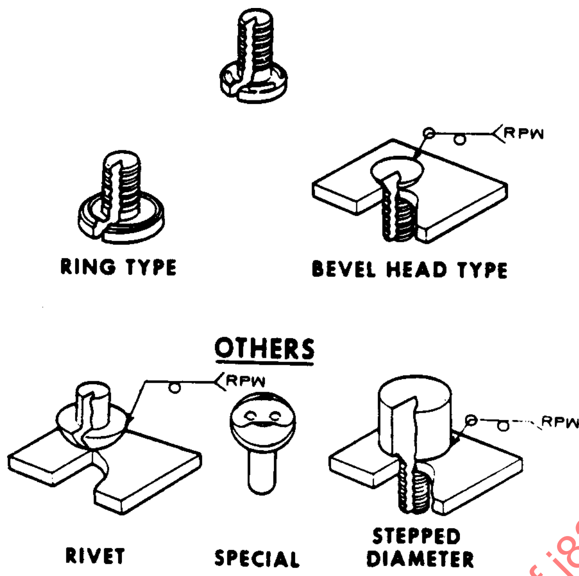


FIGURE 14—PROJECTION WELD BOLTS

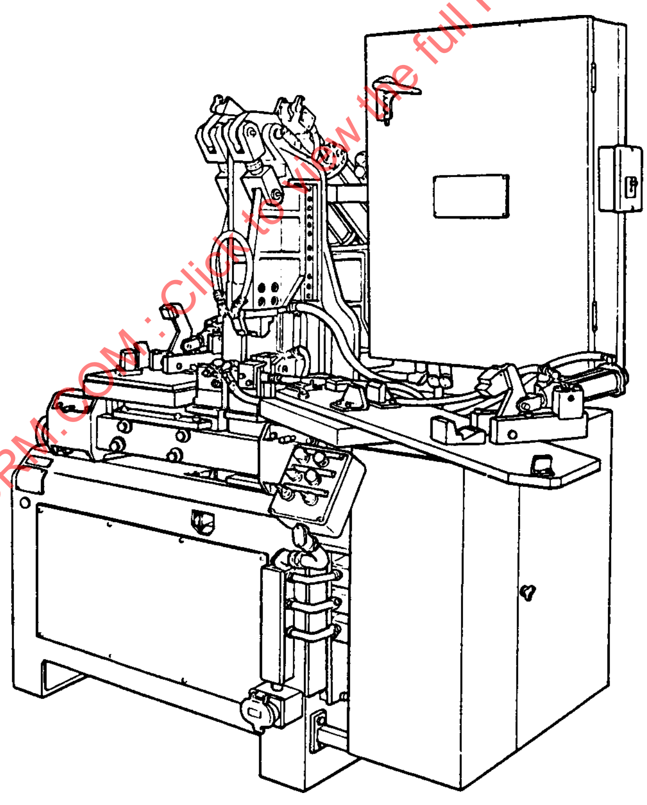


FIGURE 15—FLASH WELDING MACHINE

Typical applications are on bar and rod products (Figure 16), starter ring gear for automotive production, low carbon drill shanks to tool steel drill points, etc.

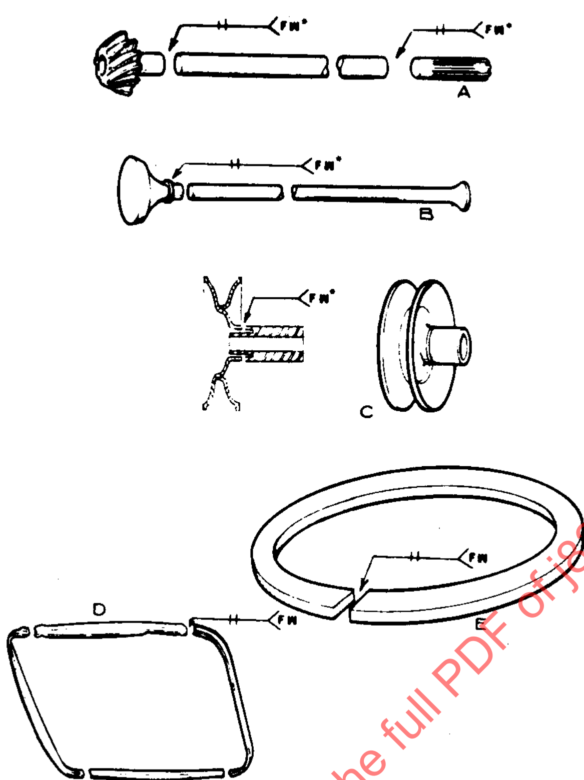


FIGURE 16—AUTOMOTIVE APPLICATIONS DESIGNED WITH GOOD FLASH BUTT WELDING FEATURES
A. Drive Shaft - Pinion, Spline, and Shaft are Made as Separate Units to Facilitate Machining, and Then Flash Butt Welded to Make Complete Drive Shaft.
B. Valve - Head is Made of Special Heat Resisting Alloy and is Flash Butt Welded to Shank.
C. Pulley - Stamping Assembly is Flash Butt Welded to Machined Part, Replacing Machined Casting.
D. Door Frame - Four Small Stampings are Flash Butt Welded to Make a Complete Frame, Avoiding Intricate Single Stamping.
E. Ring Gear Blank - Rolled Steel Strip is Formed and Flash Butt Welded, Replacing Forging.
*Flash weld joint.

3.5.1 Additional references are:

3.5.1.1 American Welding Society Welding Handbook, Fifth Edition, Section 2, Chapter 31.

3.5.1.2 Resistance Welding Manual (RWMA), Third Edition, Chapter 5, p. 67.

3.6 Upset Butt Welding—Upset butt welding is a resistance welding process wherein coalescence is produced simultaneously over the entire area of abutting surfaces or progressively along a joint by the heat obtained from resistance to the flow of electric current through the area of contact of the abutting surfaces. Force is applied before heating is started and is maintained throughout the heating period.

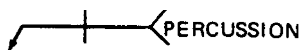
Upset butt welding was the earliest form of resistance welding. This type of butt welding has no flash and results in a smooth and symmetrical upset section. The upset butt weld is of lower strength, quality, and uniformity as compared to flash butt welding. This is primarily due to any dirt, rust, scale, or other foreign matter on the abutting surfaces that will remain imbedded in the weld.

Principal applications of upset butt welding are wire products, pipes, and tubular members.

3.6.1 Additional references are:

3.6.1.1 American Welding Society Welding Handbook, Fifth Edition, Section 2, Chapter 31.

3.6.1.2 Resistance Welding Manual (RWMA), Third Edition, Chapter 5, p. 67.



3.7 Percussion Welding—Percussion welding is defined as a resistance welding process wherein coalescence is produced simultaneously over the entire area of abutting surfaces, by heat obtained from an arc produced by a rapid discharge of electrical energy with force percussively applied during or immediately following the electrical discharge.

All percussive processes are confined to butt-welded joints. The total area that can be joined is limited to approximately 1/2 sq in, as larger areas present a problem in obtaining uniform distribution of the arcing over the entire area.

In general, this process is suitable for joining rod and tube forms to each other, or to a flat surface. The heat-affected zone is only 0.010 in deep with this process; therefore, the abutting surfaces must be finished accurately and maintained parallel to each other. See Figure 17 for equipment and operation references.

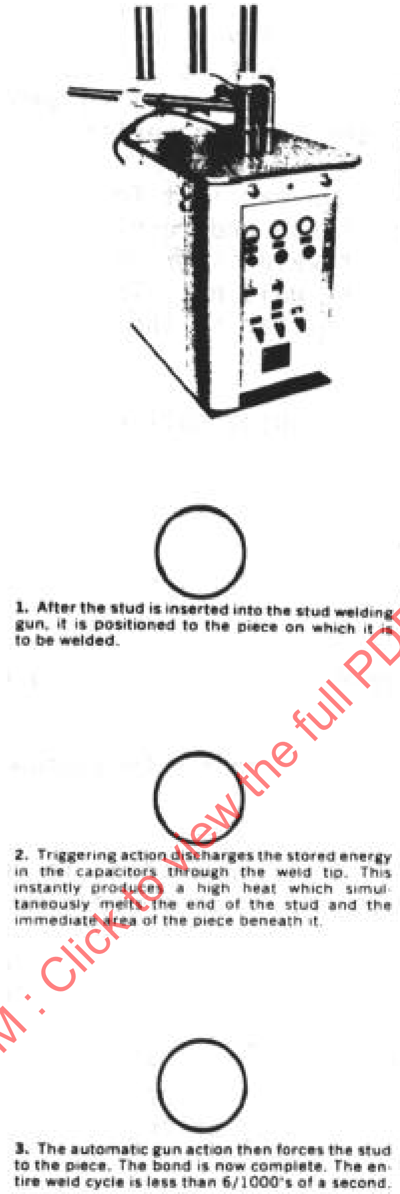


FIGURE 17—PERCUSSION WELDING MACHINE AND SEQUENCE OF OPERATION

3.7.1 Additional information can be found in:

3.7.1.1 American Welding Society Welding Handbook, Fifth Edition, Chapter 31.

3.7.1.2 Resistance Welding Manual (RWMA), Chapter 9, p. 111.

3.8 High-Frequency Resistance Welding—(No Symbol)—High-frequency resistance welding is a welding process wherein coalescence is produced by the heat obtained from the resistance of the work to the flow of an induced high-frequency electric current, with or without the application of pressure.

High-frequency resistance welding is one of the newer welding processes utilizing alternating current frequency ranges of 10–450 kc. The currents flow mainly on or near the surface of metals, and heat is generated only in the section of the metal carrying the current, resulting in a skin heating effect. The higher the current frequency, the more pronounced is the skin effect. The output of the power source is connected directly to the work to be heated by means of contact electrodes. The contacts are placed on each side of two abutting electrodes. The edges touch at one end and the rest of the joint is open to form a "V." The current flows from one contact along the edge of the "V" to its root and completes the circuit by returning along the opposite edge to the second contact. The skin effect produces localized high-intensity heating on the surface, so that welding temperature is reached as pressure is applied to the root of the "V." Heat and pressure form an upset weld, and the upset is controlled by beveling and/or a trim operation. Diagrammatic sketches of high-frequency welding are shown in Figures 18 and 19.

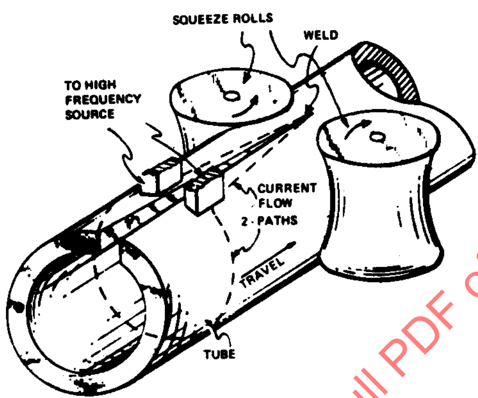


FIGURE 18—DIAGRAMMATIC SKETCH OF HIGH-FREQUENCY RESISTANCE WELDING EQUIPMENT FOR TUBE WELDING (COURTESY: THERMATOOL DIV., AMF CO.)

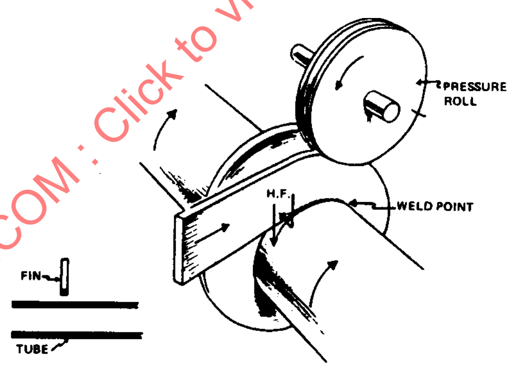


FIGURE 19—DIAGRAMMATIC SKETCH SHOWING METHOD OF WELDING SPIRAL FINS TO TUBE WITH HIGH-FREQUENCY RESISTANCE WELDING PROCESS (COURTESY: THERMATOOL DIV., AMF CO.)

3.8.1 ADVANTAGES

3.8.1.1 Applicable to a variety of metals and to a combination of dissimilar metals.

3.8.1.2 High welding speeds, up to 1000 ft/min on light-gage materials.

3.8.1.3 Applicable to highly automated fabrication lines.

3.8.1.4 A high-efficiency process which operates from a balanced 3-phase system.

3.8.1.5 Produces high-quality welds requiring no additional filler metal.

3.8.1.6 Narrow heat affected zone due to localized heating.

3.8.2 DISADVANTAGES

3.8.2.1 Higher equipment and installation costs, as compared to arc welding processes.

3.8.2.2 Requires skilled personnel for setup and maintenance.

3.8.2.3 Requires trimming or planishing of upset.

3.8.3 APPLICATIONS

3.8.3.1 Tube mills.

3.8.3.2 Structural shapes such as Is, Ts, channels, and box sections.

3.8.3.3 Butt welds in tubing and pipes.

3.8.4 REFERENCES

3.8.4.1 American Welding Society Welding Handbook, Fifth Edition, Section 2, Chapter 35 (1964).

3.8.4.2 W. C. Rudd, "High Frequency Resistance Welding." Welding Journal, Vol. 36, July 1957, pp. 703–707.

3.8.4.3 "Modern Joining Processes," Chapter 5, p. 51. American Welding Society (1966).

4. Arc Welding—Arc welding is a term applied to a group of welding processes wherein coalescence is produced by heating with an electric arc or arcs, with or without the application of pressure and with or without the use of filler metal. The original arc welding processes, originated in the 1880s, utilized carbon or unshielded bare metal electrodes, manually held and guided along the desired path to produce a welded joint. Since that time, many advances and improvements have been made. Arc welding processes currently in common usage within the automotive industry include:

1. Shielded metal-arc welding (coated electrode) (Figure 20).
2. Submerged arc welding (Figure 21).
3. Gas tungsten-arc welding (Figure 22).
4. Gas metal-arc welding (Figure 23).
5. Stud welding.
6. Flux-cored arc welding.
7. Arc spot welding.

The various arc welding processes have evolved from advances in electrode, from advances in shielding methods and materials to protect the fusion zone and deposited metal from atmospheric contamination, or from specialized uses. Further descriptions of these arc welding processes are as follows:

4.1 Shielded Metal Arc Welding (SMAW)—This is the name of the process wherein heating is obtained from an arc between a covered metal electrode and the work. The decomposition of the electrode covering, at arc temperatures, provides a shielding atmosphere. Filler metal is obtained from the melted electrode. Commonly referred to as manual stick electrode arc welding, this process was for years by far the foremost welding process.

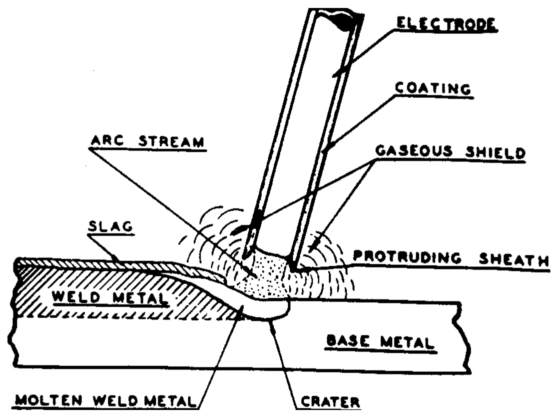


FIGURE 20—SHIELDED METAL-ARC WELDING (COATED ELECTRODE) PROCESS

FIGURE 21—CUTAWAY VIEW OF SUBMERGED ARC WELDING PROCESS (COURTESY: LINDE AIR PRODUCTS UNIONMELT WELDING HANDBOOK, 1953)

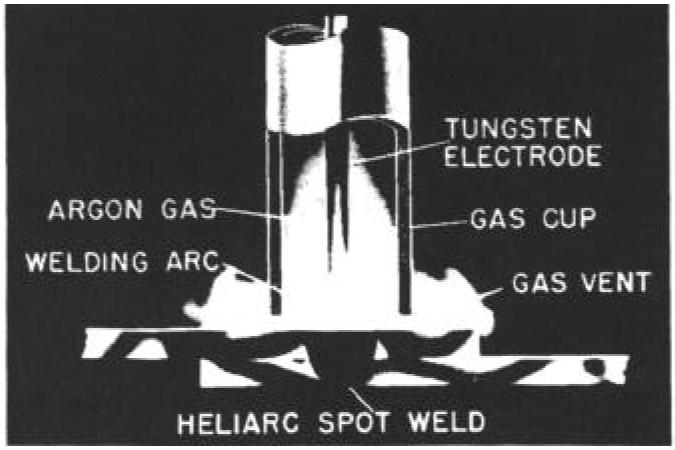


FIGURE 22—GAS TUNGSTEN-ARC WELDING PROCESS

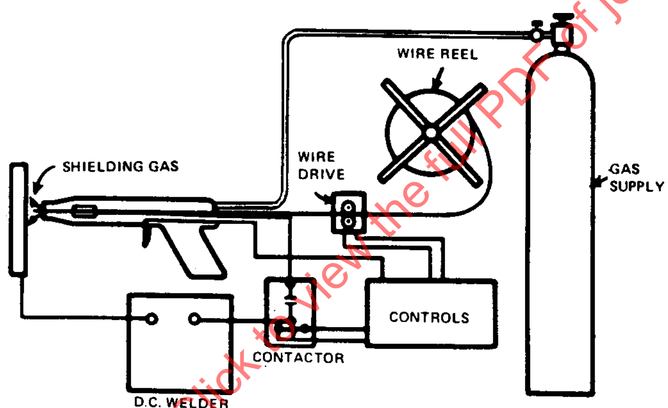


FIGURE 23—GAS METAL-ARC WELDING PROCESS

4.1.1 ADVANTAGES

4.1.1.1 Simple, rugged equipment available.

4.1.1.2 Very flexible and portable equipment, either electric or gas engine power, can be used.

4.1.1.3 Electrodes commercially available for most weldable ferrous materials and many nonferrous metals. This is particularly true with the new materials coming on the market.

4.1.2 DISADVANTAGES

4.1.2.1 Requires considerable operator skill.

4.1.2.2 Difficult to automate due to coating on electrode.

4.1.3 APPLICATIONS

4.1.3.1 Frame and chassis components.

4.1.3.2 Casting repair.

4.1.3.3 Equipment, tooling, construction, and maintenance.

4.1.3.4 Die construction and repair.

4.1.3.5 Equipment maintenance.

4.1.4 REFERENCE—American Welding Society Welding Handbook, Fifth Edition, Section 2, Chapter 25.

4.2 Submerged Arc Welding (SAW)—A welding process in which an arc between a bare consumable electrode and the work provides the heat for welding with shielding being provided by a blanket of granular fusible material on the work. Normally this process is considered for automatic applications using high currents, high-duty cycle, and multiple work on heavy weldments. Some light-gage applications have been successful, but for the most part this type of joining has shifted to the newer gas metal-arc welding or flux-cored arc welding processes, particularly for 0.125 in thick and under.

4.2.1 ADVANTAGES

4.2.1.1 Flux can hold weld metal in position on light-gage horizontal welds with base metal in the vertical plane.

4.2.1.2 Smooth external bead contour gives excellent appearance.

4.2.1.3 Uses coil stock electrode - minimum waste.

4.2.1.4 Can have very high deposition rates.

4.2.2 DISADVANTAGES

4.2.2.1 Abrasive flux difficult to contain causing equipment wear, especially material handling and housekeeping problems.

4.2.2.2 Separate flux presents handling problems both before welding and after the weld is completed.

4.2.3 APPLICATIONS

4.2.3.1 Chassis components.

4.2.3.2 Transmission components.

4.2.4 REFERENCE—American Welding Society Welding Handbook, Fifth Edition, Section 2, Chapter 28.

4.3 Gas Tungsten-Arc Welding (GTAW)—The necessary heat for gas tungsten-arc welding is produced by an arc between a nonconsumable electrode (usually tungsten or tungsten alloy) and the work. The heated weld zone, molten metal, and electrode are shielded by an inert gas. If additional filler metal is required over and above the melted workpiece, it is supplied by inserting filler rods into the weld zone. The process is adaptable to both manual and automatic equipment. Due to the partial rectification of the current flow in an arc between tungsten and the commonly used nonferrous base metals and the differences in types of current flow and surface cleaning, care should be exercised in the selection of equipment between direct and alternating current types and shielding gas to insure obtaining the ones best suited for the application.

4.3.1 ADVANTAGES

4.3.1.1 Process capable of producing high-quality welds in a wide variety of base metals.

4.3.1.2 Concentrated heat produces less distortion than gas welding with oxygen-fuel gas flame process.

4.3.1.3 Low amperage permitting smaller power source and gun.

4.3.2 DISADVANTAGES

4.3.2.1 Close control is required in maintaining a shore arc length.

4.3.2.2 High maintenance as compared to shielded metallic arc processes.

4.3.2.3 Part fit-up must be held to close tolerances with clean surfaces.

4.3.3 APPLICATIONS

4.3.3.1 Well suited for nonferrous components.

4.3.3.2 Die maintenance.

4.3.4 REFERENCE—American Welding Society Welding Handbook, Fifth Edition, Section 2, Chapter 27.

4.4 Gas Metal-Arc Welding (GMAW)—The necessary heat for gas metal-arc welding is produced by an arc between a consumable metal electrode and the work. The arc and weld puddle are shielded by an externally supplied gas, gas mixture, or, on rare occasion, by a mixture of gas and flux. The electrode feed is always mechanically driven. The process is used considerably with both operator guided (semiautomatic) and mechanically guided (automatic) torches. Since its introduction (about 1950) the process has grown very rapidly. The most common shielding gases are argon, carbon dioxide, helium, and their mixtures. Small amounts of oxygen are sometimes added to improve arc stability.

4.4.1 ADVANTAGES

4.4.1.1 No electrode loss such as unused stubs by using electrode in coils.

4.4.1.2 Little or no cleaning of deposit required.

4.4.1.3 Adaptable to wide range of metal thicknesses.

4.4.1.4 High deposition with deep penetration.

4.4.2 DISADVANTAGES

4.4.2.1 Higher maintenance than shielded metallic arc processes.

4.4.2.2 Air currents may disrupt gas shield.

4.4.2.3 Spatter may block shielding gas especially in out-of-position work.

4.4.3 APPLICATIONS

4.4.3.1 Frames.

4.4.3.2 Chassis components.

4.4.3.3 Body sheet metal joints with fine wire type.

4.4.3.4 Ferrous or nonferrous components.

4.4.4 REFERENCE—American Welding Society Welding Handbook, Fifth Edition, Section 2, Chapter 27.

4.5 Flux-Cored Arc Welding (FCAW)—This is an arc welding process wherein coalescence is produced by an electric arc between a consumable metal electrode and the work with shielding primarily obtained from a flux contained within the electrode. Additional shielding may or may not be obtained from an externally supplied gas or gas mixture. The discovery or development of flux-cored electrodes and the ability to make them commercially has brought this process into being. Best used on 0.0625 in material or heavier.

4.5.1 ADVANTAGES

4.5.1.1 Can be used without shielding gas.

4.5.1.2 High deposition rate produced.

4.5.1.3 Adaptable to both automatic and semiautomatic use with coiled electrode.

4.5.1.4 Less prone to undercutting than solid wire type.

4.5.1.5 Good for out-of-position work.

4.5.2 DISADVANTAGES

4.5.2.1 Material cost.

4.5.2.2 Possibility of having irregular flux core without detection.

4.5.3 APPLICATIONS

4.5.3.1 Drive shaft assembly.

4.5.3.2 Control arm.

4.5.3.3 Differential housing.

4.5.3.4 Frame assemblies used on 0.060 or heavier material.

4.6 Arc-Spot Welding—An arc welding method where coalescence at the faying surfaces is produced in one spot by heating with an electric arc between either a consumable or nonconsumable electrode and the work. The weld is made with or without preparing a hole in upper member. Shielding gas or flux may or may not be used. Any of the arc welding processes previously described may be used to perform arc-spot welding. However, the gas tungsten arc or gas metal arc processes are most often adopted. An arc timer control is added to conventional equipment to produce an arc-spot welding machine.

4.6.1 ADVANTAGES

4.6.1.1 Access to only one side of joint required.

4.6.1.2 Minimum operator skill required.

4.6.1.3 Applicable to wide range of thicknesses.

4.6.1.4 Nominal equipment cost.

4.6.2 DISADVANTAGES

4.6.2.1 Very good fit-up and clean materials are required to get good quality welds with gas tungsten-arc process.

4.6.2.2 Limited in positions welding can be performed because gravity will cause run-out of molten metal.

4.6.2.3 Equipment maintenance.

4.6.3 APPLICATIONS

4.6.3.1 Ferrous and nonferrous assemblies.

4.6.3.2 Truck and tractor frame components.

4.6.4 REFERENCE—American Welding Society Recommended Practices for Automotive Welding Design D8.4–61.

4.7 Stud Welding (SW)—Stud welding is an arc welding process wherein coalescence is produced by heating with an electric arc between a metal stud and the workpiece to heat the stud end and work surface before they are brought together under plunge force. Shielding may or may not be obtained by flux tipped studs, ceramic ferrules, or shielding gas, depending on size and material.

4.7.1 ADVANTAGES

4.7.1.1 Minimum operator skill required.

4.7.1.2 Can be automated for high-speed operation.

4.7.2 DISADVANTAGES

4.7.2.1 Complexity can cause it to be high-maintenance item.

4.7.2.2 Stud costs may be high.

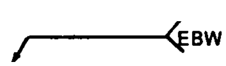
4.7.3 APPLICATIONS

4.7.3.1 Trim and hardware attachment to bodies and fenders.

4.7.3.2 Ferrous and nonferrous components and some combinations.

4.7.4 REFERENCE—American Welding Society Welding Handbook, Fifth Edition, Section 2, Chapter 29.

5. Special Welding Processes



5.1 Electron Beam Welding—Electron beam welding is a process wherein coalescence is produced by the heat obtained from a concentrated beam composed primarily of high-velocity electrons impinging upon the surfaces to be joined. Electron beam welding is done in three modes:

1. Hard vacuum (see Figure 24).
2. Soft or partial vacuum.
3. Out-of-chamber or atmosphere welding.

Further descriptions of these three modes follow:

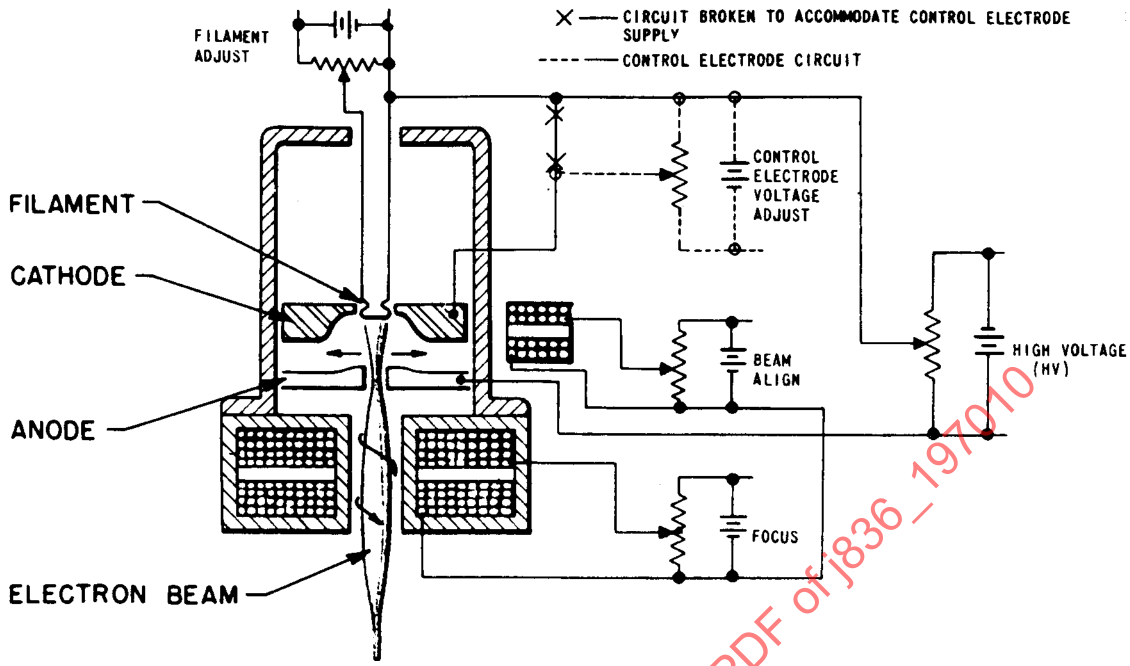


FIGURE 24—ELECTRON BEAM GUN AND ASSOCIATED CONTROLS (COURTESY: SCIAKY BROTHERS, INC.)

5.2 Hard Vacuum—This mode of welding is done in a chamber usually evacuated to a vacuum level of 1 x 10^{-4} Torr or 0.1 micron Hg.

5.2.1 ADVANTAGES

5.2.1.1 Has the ability to make welds with extremely high depth-to-width ratio; that is, a 1/6 in wide butt weld in a 1/2 in thick plate.

5.2.1.2 Approximation of true parallelism of the weld sides (minimum of "V" shape) to minimize distortion.

5.2.1.3 Welds created with a minimum of energy and therefore, minimal heat-affected zones.

5.2.1.4 Extremely small-diameter heat source.

5.2.1.5 High welding speeds.

5.2.1.6 Purity of vacuum melt metals.

5.2.1.7 Permits welding of refractory or highly active materials such as molybdenum, tantalum, tungsten, etc.

5.2.2 DISADVANTAGES

5.2.2.1 High equipment cost.

5.2.2.2 Parts to be welded must be housed in a vacuum chamber; the evacuation time can be long depending on chamber size.

5.2.2.3 Weld joint must fit within thousandths of an inch.

5.2.3 APPLICATIONS

5.2.3.1 Cluster gears.

5.2.3.2 Any precision part where maximum weld integrity is necessary.

5.2.3.3 Aerospace components.

5.2.4 REFERENCE—American Welding Society Welding Handbook, Fifth Edition, Section 3, Chapter 54.

5.3 Soft or Partial Vacuum—This mode of welding is usually done in a small chamber specifically designed to fit around the weldment with a minimum of clearance. As a result, a minimum of atmosphere must be evacuated.

The vacuum level is usually 50 microns Hg or 5 x 10^{-2} Torr.

5.3.1 ADVANTAGES

5.3.1.1 For all practical purposes, all of the advantages listed for "hard vacuum" welding apply with the possible exception of the ability to weld the refractory or highly active metals.

5.3.1.2 Evacuation time is reduced to seconds rather than minutes, thereby increasing production output.

5.3.2 DISADVANTAGES

5.3.2.1 High equipment cost.

5.3.2.2 Weld joint must fit within thousandths of an inch.

5.3.3 APPLICATIONS

5.3.3.1 Cluster gears.

5.3.3.2 Any precision weldment where maximum weld integrity is required.

5.3.3.3 Any precision weldment where premachining and/or preheat treatment is of prime consideration.

5.4 Out-of Chamber Welding—This mode of welding is a rather specialized version. The description "out-of-chamber" can be misleading in that it infers no vacuum is required. This is not completely true. The weldment is accomplished at atmospheric pressure; however, the equipment incorporates, by necessity, a pressure gradient from the gun to the workpiece which includes both a "hard" and a "soft" vacuum.

5.4.1 ADVANTAGES

5.4.1.1 The need and expense of a vacuum-tight welding chamber are eliminated.

5.4.1.2 Because of the nonvacuum environment, tooling problems are reduced.

5.4.2 DISADVANTAGES

5.4.2.1 The high depth-to-width ratio of the weld configuration is reduced almost to that obtained with "GTAW" welding.

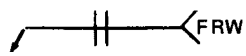
5.4.2.2 Maximum gun-to-workpiece distance is reduced from 30–50 in to 1/2 in. This severely limits the area of application due to mechanical interference.

5.4.2.3 At the present state-of-the-art, approximately 150 kV appears to be the minimum practical operating voltage. At this level, significant levels of x-ray radiation and ozone are present, necessitating shielding and ventilation far beyond what is required in the other two modes.

5.4.3 APPLICATIONS

5.4.3.1 Tube mills.

5.4.3.2 Transmission and/or differential housings.



5.5 Friction Welding—Friction welding is a solid-state welding process wherein coalescence is produced by the heat obtained from mechanically induced sliding motion between rubbing surfaces. The work parts are held together under pressure.

A common scheme for friction welding is one in which two cylindrical bars (Figure 25) are axially aligned, one of which is rotated while the other is held stationary. The angular speed of the rotating member and the axial force at the rubbing ends of the bars are regulated so as to develop sufficient frictional heat and metal displacement for welding.

5.5.1 ADVANTAGES

5.5.1.1 Welds a wide variety of dissimilar materials and cross sections. Exception—most cast irons do not lend themselves to this process due to low coefficient of friction.

5.5.1.2 Produces welds of excellent quality at very high rates.

5.5.1.3 Weld zone is wrought structure rather than cast due to push out of molten metal during the welding process.

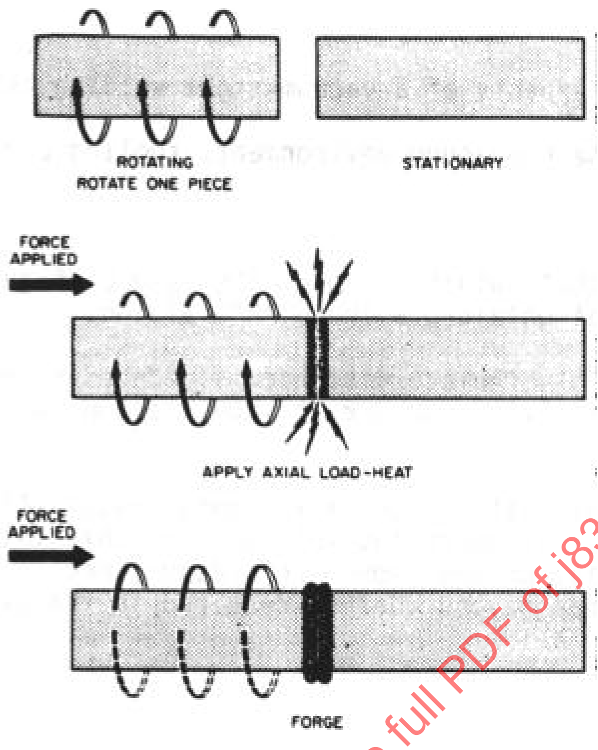


FIGURE 25—FRICTION WELDING

5.5.1.4 Weld zone is very narrow with nearly parallel sides. This keeps shrinkage stresses in one plane.

5.5.1.5 Heat-affected zone is usually very narrow by comparison to arc welding processes.

5.5.1.6 Rugged equipment readily available.

5.5.1.7 Process is fully automatic, keeping operator skill requirement to a minimum.

5.5.1.8 Very little if any joint preparation required.

5.5.1.9 Low maintenance.

5.5.2 DISADVANTAGES

5.5.2.1 High equipment cost.

5.5.2.2 One member of joint should be rotationally symmetrical. It is virtually impossible to maintain rotational orientation from one member to another across the face of the joint.

5.5.2.3 Premachining concept of fabrication is possible to only a limited degree, due to the problem of maintaining concentricity across the joint. This varies tremendously depending on the type of material being welded and the total cross-sectional area of joint.

5.5.3 APPLICATIONS

5.5.3.1 Worm gears to rod.

5.5.3.2 Valve stems to valve head.

5.5.3.3 Alloy steel tool joints to drill pipe for oil wells.

5.5.3.4 Copper circuit breaker assemblies.

5.5.3.5 Sprocket gears to hubs.

5.5.3.6 Some combinations of nonferrous materials to ferrous materials.

5.5.4 REFERENCE—American Welding Society Welding Handbook, Fifth Edition, Section 3, Chapter 52.

5.6 Laser Beam Welding (LBW)—A welding process wherein coalescence is produced by the heat obtained from the application of a concentrated coherent light beam impinging upon the surfaces to be joined.

A laser is a device which produces a concentrated coherent light beam through the manipulation and control of energy exchanges in solid-state transparent media. Welding may be accomplished by causing this light beam to impinge upon the surfaces to be joined.

Solid-state lasers are based on transparent single crystals or vitreous substances which contain small concentrations of transition elements. The transition element atoms can be excited to various levels upon exposure to intense optical radiation. As with other welding processes, the amount of metal melted depends upon the intensity and total energy transferred by the laser beam.

5.6.1 ADVANTAGES

5.6.1.1 The high-intensity beam can be focused to extremely small spot diameters by optical focussing, rivaled only by the electron beam.

5.6.1.2 Since the laser delivers its energy in the form of light, it can be operated in any transparent environment - air, vacuum, inert gas, or even certain liquids, and through transparent windows - and need not be in close proximity to the workpiece.

5.6.1.3 There is no need for mechanical contact of any kind with the workpiece.

5.6.1.4 There is no need for the material being welded to be a conductor of electricity.

5.6.2 DISADVANTAGES

5.6.2.1 The pulse durations are so short, at most a few milliseconds, and the "off" times so relatively long between pulses, that the metal melted by a pulse of energy has completely solidified and cooled before another pulse can be delivered. As laser technology progresses, continuous lasers capable of welding will very probably evolve.

5.6.2.2 The efficiency (at the present state-of-the-art) is quite low; power input to power output.

5.6.2.3 Present area of application is limited to joining of small diameter wires of metals of foil thicknesses.

5.6.3 APPLICATIONS

5.6.3.1 Wire-to-wire welds.

5.6.3.2 Sheet-to-sheet welds (up to approximately 0.040 thickness).

5.6.3.3 Wire-to-sheet welds.

5.6.4 REFERENCE—American Welding Society Welding Handbook, Fifth Edition, Section 3, Chapter 56.

5.7 Ultrasonic Welding—Ultrasonic welding is a process for joining similar and dissimilar metals by the introduction of high-frequency vibratory energy into the overlapping metals in the area to be joined. No fluxes or filler metals are used, no electrical current passes through the weld metal, and usually no heat is applied. The workpieces (Figure 26) are clamped together under moderately low static force, and ultrasonic energy is transmitted into the intended weld area. A sound metallurgical bond is produced without arc or melting of the weld metal and without the cast structure associated with melting. There is minor thickness deformation.

5.7.1 ADVANTAGES

5.7.1.1 Permits welding of many metals and alloys and combinations thereof.

5.7.1.2 Permits welding of certain joints with geometrical configurations that are difficult or impossible to join by other techniques.

5.7.1.3 Eliminates cast structure of weld.

5.7.1.4 Heat input is so low that most side effects of heating produced by other techniques are minimized or eliminated.

5.7.1.5 Power requirements are very low compared to other welding processes.

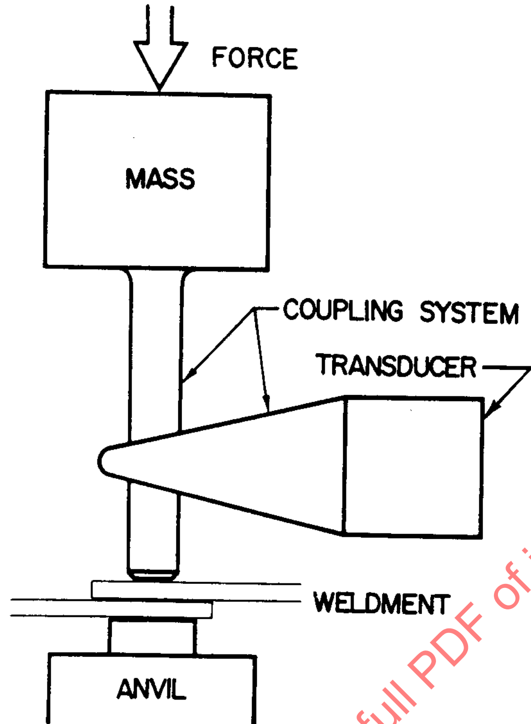


FIGURE 26—SCHEMATIC OF ULTRASONIC PROCESS

5.7.2 DISADVANTAGES

5.7.2.1 Is limited in metal thicknesses the process can handle. Maximum thickness is approximately 0.10 in. Some metals may be limited to as low as 0.015-0.040 in. There appears to be no lower limit; foils as thin as 0.00017 in have been welded.

5.7.2.2 Tip sticking, that is, tip welding itself to the part, can be troublesome.

5.7.2.3 Design requirements make accessibility to odd shaped joints limited compared to resistance welding.

5.7.3 APPLICATIONS

5.7.3.1 Electronic components.

5.7.3.2 Fine wires and thin foils.

5.7.3.3 Encapsulating materials that are heat sensitive such as pyrotechnics, explosives, reactive chemicals, and pharmaceuticals.

5.7.4 REFERENCE—American Welding Society Welding Handbook, Fifth Edition, Section 3, Chapter 49.

6. Brazing—Brazing is a term applied to a group of welding processes wherein coalescence is produced by heating to a suitable temperature above 800 °F and by using a nonferrous filler metal, having a melting point below that to the base metals. The filler metal is distributed between the closely fitted surfaces of the joint by capillary attraction. Some of the most commonly used brazing processes in the automotive industry are: