ULTRAPULSE WELDING: A NEW JOINING TECHNIQUE

David G. Anderson
Director of Research and Development
The Quanta Welding Company
Troy, Michigan

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The Ultrapulse* welding (UPW) process is a relatively new form of resistance welding. UPW can be used for spot welding but most applications have been in the projection and butt welding areas. The purpose of this paper is to describe the UPW process as it applies to the automotive industry. The principles of UPW will be discussed, followed by a description of a number of automotive applications and finally by some UPW advantages and its limitations.

PRINCIPLES OF ULTRAPULSE WELDING

The Ultrapulse process is a resistance welding process that utilizes unidirectional current of high magnitude for a very short time with a precisely controlled dynamic force pulse. Peak currents of up to 220,000 amperes for two to ten milliseconds are used with synchronized force pulses of up to nine thousand pounds. Welding force and current pulses for a typical UP weld are shown on Fig. 1. The welding current passing through the relatively high resistance of the interface between the parts that are being joined results in highly localized heating. The

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*Trademark of Quanta Welding Company, Troy, Michigan combination of localized heating at the mating surfaces and the force application results in the parts being forged together into a solid-state weld.

The short duration of the welding current and accurate control of all process elements limit heat generation to the immediate area of the interface being welded. The weld time is not long enough to cause the metal surrounding the welded interface or the electrodes to be heated to a high enough temperature for significant metallurgical changes to take place. The solid-state weld nearly eliminates the melting and mixing of the parts being joined at the weld interface. The unique localized heating at the interface also lessens the extensive grain size and phase changes normally encountered in resistance and arc welding. This makes it possible to join a variety of heat-treated and heat-sensitive alloys and dissimilar ferrous metals, with no deleterious effects on their physical properties. Dissimilar metal thicknesses are also welded with relative ease compared to other processes.

Conventional resistance welding is accomplished at lower welding current, but requires weld times on the order of fifty to one hundred times as long as Ultrapulse. These longer times result in greater heat losses, melting at the interface, metallurgical transformations in the area surrounding the weld, distortion of the weldment as a result of extensive heating and rapid cooling, and heating of the electrodes.

AUTOMOTIVE APPLICATIONS OF UPW

UPW has been applied successfully to a variety of automotive parts. These applications have involved a number of materials, material combinations and joint designs. Examples which are cited here are typical of this family of parts.

Valve Lifter

This part consists of a cylindrical body (approximately one inch in diameter and two inches long) and a tip (approximately one inch in diameter and 0.1 inches thick). The body is made by conventional powder metallurgy techniques, using iron powder and graphite. An annular projection on the as-sintered body provides the necessary concentration of welding force and current for UP welding. The tip is a white cast iron disc; both planar surfaces are ground to assure parallelism and to provide a flat surface for welding.

Each weld pulse produces a welded part; weld time is approximately 0.010 seconds. The weld is angularly continuous (leak-tight) and is about 0.080 inches wide. The shear strength of the weld is 8,000 pounds. A photograph of the weld interface is shown on Fig. 2.

Automatic Choke Thermostat

One car manufacturer uses an automatic choke thermostat which includes a die-cast aluminum base and a machined thermostat shaft of aluminum alloy. The shaft is presently welded to the base by the manual gas tungsten-arc ("TIG") welding process. Shortcomings of this method are: (1) the gas tungsten-arc process is slow, (2) considerable operator skill is required, (3) a prior crimping operation is required to locate the shaft and to prevent its motion during welding, (4) expulsion occasionally is ejected into the coiled thermostat and produces a reject-part, (5) arc shielding and exhaust of fumes are necessary, and (6) the heat from the arc may be sufficient to move the thermostat from its calibrated position.

Ultrapulse welding has been used successfully for this application. Both ends of the shaft were UP welded in one weld pulse, without the need for prior crimping. A photograph of thermostats made by the two methods is shown on Fig. 3. The left part was crimped and then GTA welded; the right part was UP welded.

Distributor Cam

This part consists of two low carbon steel components: a machined tubular shaft and a flat stamping with a bored hole.

The relative angular position of the stamping on the shaft is critical. The manufacturer presently uses interference dimensions to produce a press-fit. The mechanically-fastened parts are then brazed.

The alternate assembly method employs UPW. The weld tooling locates the parts, eliminating the press-fit requirement. Gross production rate is estimated to be 1,500 parts per hour. A photograph of a UP welded distributor cam is shown on Fig. 4.

Connector

Connectors for fluid lines are conventionally made by three methods: (1) machining in one piece, (2) brazing two component parts, or (3) resistance welding two component parts. The first method permits the use of free-machining steels, but costs may be relatively high, due to the larger volume of metal that must be removed by machining. Connector components made from free-machining steels are difficult to resistance weld, so machining costs are higher for resistance welded connectors.

UP-welded connectors can be made from free-machining steel (e.g. AISI-1108). This permits the use of lower cost components and a high production rate joining technique. A typical UP-welded connector is shown on Fig. 5.

Attachment to Glass Plate

Attachments of metal parts to glass has been achieved with UPW. This is done by inserting a rivet-shaped stud into a hole in the glass and UP welding the stud end to a metallic part, thus securing the metallic part to the glass. The welds are achieved with these effects: (1) the glass is not damaged by the low "weld heat", (2) the stud remains at near-room temperature except in the immediate region of the weld (i.e. the stud diameter is unchanged), and (3) the shortening of the stud during welding is slight and repeatable (0.005 to 0.006 inches is typical). See Fig. 6 for a photograph of a window hinge attached to tempered glass plate by the UPW process.

Chrome-Plated Steel

Chrome-plated steel parts have been UP welded without damaging the plating. This permits the twin economies of lower plating costs (e.g. plate only one part) and high speed welding capability. Fig. 7 shows two coupons that have been UP welded. Both coupons are SAE-950 steel approximately 0.12 inches thick. The upper coupon was plated before welding; the lower one was not plated. A projection was formed in the non-plated coupon prior to UP welding. The shear strength of the weld was over 3,000 pounds.

Attachment to Vinyl-Coated Steel

UPW has been used to weld to vinyl-coated steel sheet without damaging the decorative vinyl. Such a weld is shown on Fig. 8. An annular projection was machined on the nut prior to welding. In this example, the weld diameter was 0.35 inches and the thickness of the steel sheet was 0.040 inches.

Exhaust Valve Tip

The requirement is to produce an exhaust valve with a hardened R_C 50 tip on the stem. The exhaust valve is an austenitic steel; the tip is AISI-8740 alloy steel. The conventional method employs a resistance welder to projection weld an annealed tip to the end of the exhaust valve stem. The tip is subsequently induction hardened, prior to the final machining operations.

Ultrapulse welding has been used to weld pre-hardened tips to these exhaust valve stems, without tempering the wear surface of the tip. Fig. 9 shows a UP-welded exhaust valve in the as-welded condition. Weld microstructure is shown on Fig. 10. The lighter region is the valve stem material; the darker region is the tip. The extremely narrow heat affected zone is indicated by the width of the tempered zone in the tip (less than 0.008 inches).

ADVANTAGES OF ULTRAPULSE WELDING

The UP-welded products which have been described in this paper embody several of the product advantages of UP welding. These advantages are summarized here, as well as the characteristic advantages of UP equipment.

Weld Finished or Semi-Finished Parts

The high thermal efficiency and low heat input of UPW permits finished (e.g. ground surface) parts to be welded. This is in contrast with other welding processes which may require weld flash or upset weld metal to be removed. The welding of finished parts permits substantial reduction of machining costs. In many instances, parts can be case-hardened and finish-ground prior to UP welding. This permits selective hardening without the use of stop-offs and more efficient use of available furnace space.

Dimensional Accuracy of As-welded Parts

The very rapid heating rate and the subsequent localized heating zone produce dimensional changes only in the immediate area of the weld. The width of a typical dimension-affected zone (DAZ) is 0.020 inches. The narrow and reproducible DAZ enables high-tolerance parts to be UP welded to a high degree of accuracy.

This accuracy includes both the location of the weld and the overall length (or thickness) of the welded assembly.

As an example of the dimensional capabilities of the UPW process, consider the following example. Two parts are finish-ground before UP welding. In a sampling of 100 parts, the as-welded parts were concentric within 0.0055 inches total indicator reading. Axial shortening of the parts during welding varied from a minimum of 0.0057 inches to a maximum of 0.0069 inches, a range of 0.0012 inches. The parts were also measured for perpendicularity. The total indicator reading at a diameter of one inch ranged from a minimum of 0.0002 inches to a maximum of 0.0012 inches.

Unusual Metal Combinations

Some metal combinations which are non-weldable or difficult to weld with most other processes can be UP welded. Some of these unusual combinations are listed below.

1. Carbonitrided low carbon steel to "hardenable" cast iron.
2. Sintered iron powder to white cast iron.
3. Carburized low carbon steel to low carbon steel.
4. A "Stellite" alloy to gray cast iron.
5. Low carbon steel to gray cast iron.
6. Chrome-plated SAE-950 steel to bare SAE-950 steel.

7. Re-sulfurized free-machining steels.
8. Porous low-density nickel structure to stainless steel.
9. Austempered AISI-8620 to cold-drawn low-carbon steel.

Weld Near Heat-Sensitive Materials

Various thermally-sensitive assemblies have been successfully welded by the UP process. Five of the parts which were described earlier in this paper are examples of UP-welded parts which are heat sensitive (see Figs. 3,6,7,8,9, and 10).

High Production Rates Possible

The UP weld is accomplished so quickly (e.g. 0.010 seconds) that welding time is not a significant portion of the cycle time of the welding system. The handling of parts (loading and unloading) is usually the most significant time element. The use of production aids, such as parts' feeders and dial index tables, can permit welding rates of 1,500 parts per hour.

Little Need For Water Cooling

Conventional resistance welding equipment requires water cooling of at least three components: the welding electrodes, the secondary windings of the welding transformer, and the switching devices, whether they be ignitron tubes or silicon-controlled rectifiers.

UPW equipment does not require water cooling of any component for most applications.

Low Input Power Demand

The UPW power supply is the stored-energy type. The system capacitors are charged to the desired voltage and the switch-gear turns "on" at the appropriate time to deliver the stored energy to the pulse welding transformer. The procedure is then repeated. This technique permits the capacitors to be re-charged during the parts' unloading and re-loading portions of the welding cycle. The demand placed on the power system by the UP welder is thus much lower than a conventional direct-energy resistance welder. Five KVA is a typical power demand for a UPW system; 150 KVA is typical for a conventional resistance welder.

Power Line Voltage Not Critical

The power line voltage has an important effect on the quality of welds made with conventional resistance welders. For example, a decrease of 10 percent in primary voltage will produce a 19 percent decrease in weld heat. This is not the case in UPW, however. The UPW power supplies charge to the same final welding voltage, even though the power line voltage may vary by 20 percent from its nominal value.

No Power Line Voltage Transients Caused by UPW

Other resistance welding processes may cause substantial "dips" in line voltage or put "spikes" back onto the power lines. UPW causes neither effect. The relatively slow capacitor-charging time of UPW (two seconds minimum) allows the line voltage to remain quite stable. Also, the UPW system is isolated from the power line during the duration of the weld pulse.

Good Power Factor

In conventional resistance welding, the impedance of the secondary (welding) circuit determines the power factor. Such power factors are usually quite unfavorable (e.g. 20 percent lagging) due to the relatively large value of inductive reactance in the secondary circuit. Power factor correction capacitors or synchronous motors may then be necessary to raise the power factor level of the power system to a more favorable level.

UPW equipment does not produce such a problem. The load that the power line "sees" is the capacitor-charging circuit. A typical UPW power factor is 90 percent lagging, so no power factor correction is required.

ULTRAPULSE WELDING LIMITATIONS

Weld Area

UPW requires a certain current density to produce a satisfactory weld in a given application. The UPW system has an upper limit of welding current. For ferrous materials the maximum area that can be welded with one pulse is approximately 0.25 square inches. This value cannot be attained in some applications, where part resistance or welding circuit inductance lowers the maximum current that can be produced.

Good Fit-Up Required

"Fit-up" is a measure of the quality and consistency of the two surfaces which are to be welded. Good fit-up is required for UPW, since the degree of melting and upsetting that occurs is slight. An as-cast surface on a sand casting is too rough to produce good quality UP welds. Surface finishes whose roughness exceeds 120 micro-inches RMS is also too rough for many applications.

Part Design

The design of the parts which are to be welded must permit the application of the necessary force and current magnitudes to the weld joint. The resistance of the parts determines the maximum current that can be produced. The structural properties of the parts determine the maximum force that can be applied to the parts without excessive permanent deformation occurring.

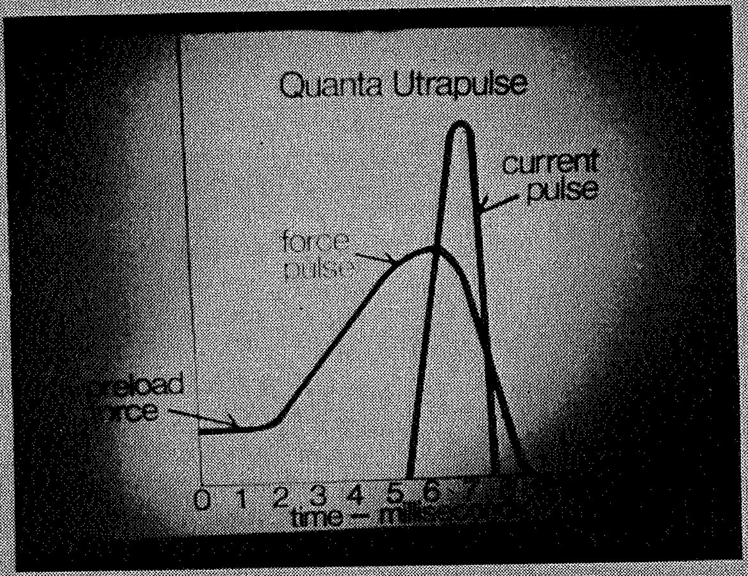

Fig. 1. Welding force and current pulses for a typical Ultrapulse weld. Note that the abscissa units are in milli-seconds.

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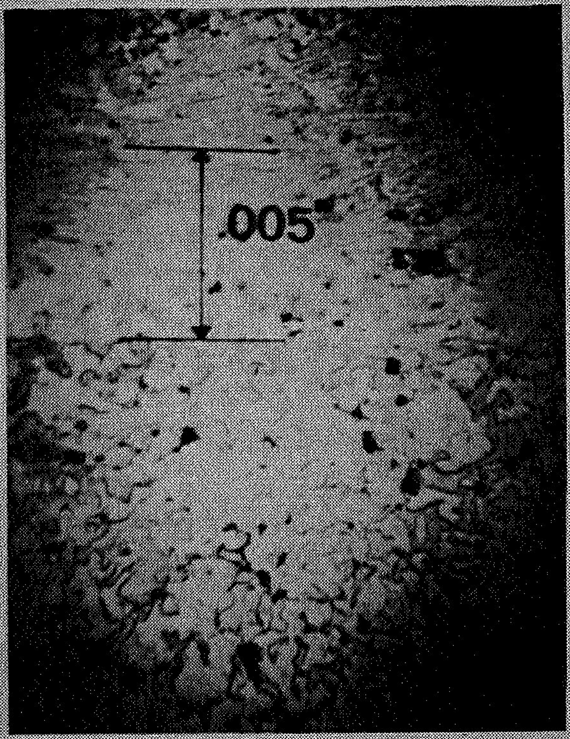

Fig. 2. Photomicrograph of an Ultrapulse-welded valve lifter. The lower material is the sintered iron body; the upper material is a white cast iron tip. Magnification is approximately 200X.

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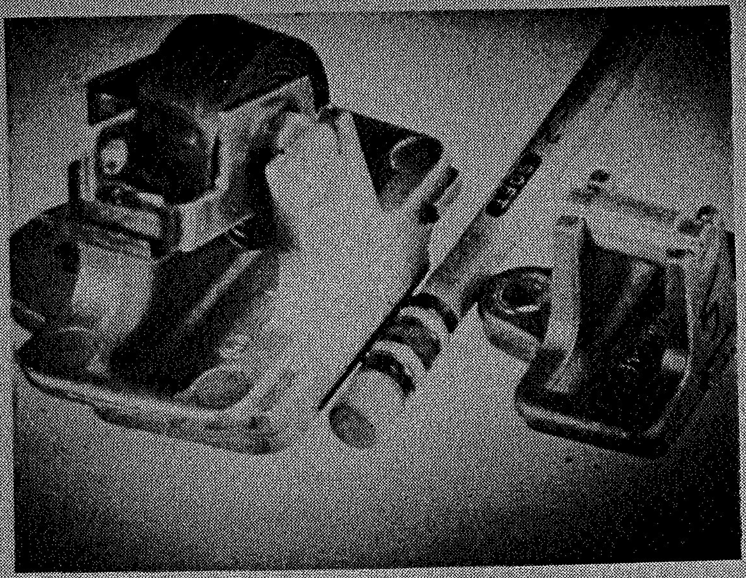

Fig. 3. Similar automatic choke thermostat components that were joined by different methods. The shaft was held in place in the left assembly by crimping; manual gas tungsten-arc welding was then used to weld one end of the aluminum shaft to the die-cast aluminum body. Both ends of the shaft were Ultrapulse welded in one pulse to the body on the right.

Fig. 4. An as-welded distributor cam that was welded by the Ultrapulse welding process.

Fig. 5. An Ultrapulse-welded connector. Both parts are free-machining steel.

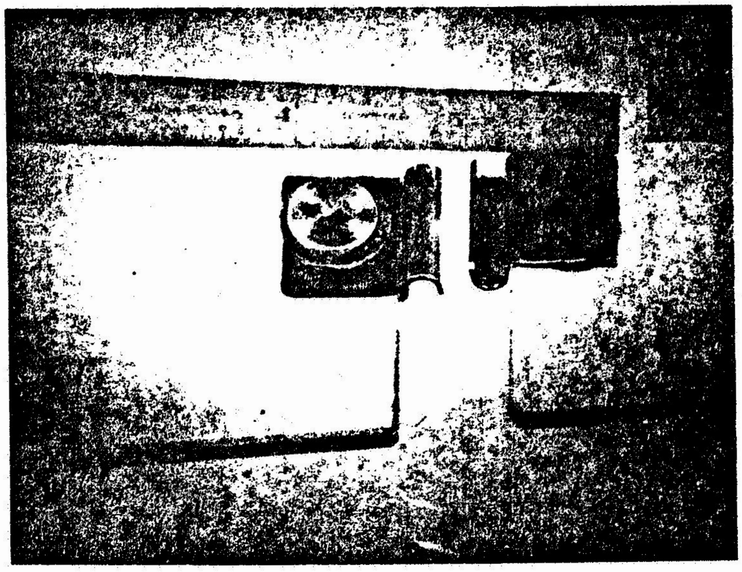

Fig. 6. Two window hinges attached to glass plates by Ultrapulse welding.

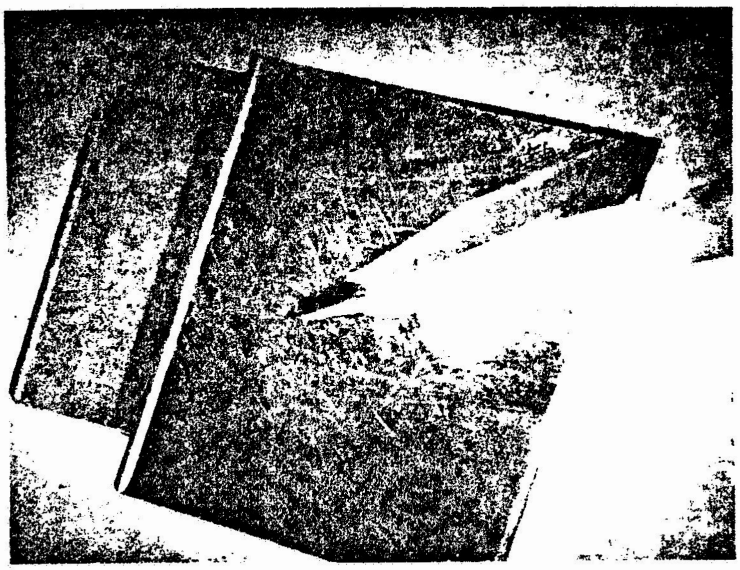

Fig. 7. Chrome-plated steel Ultrapulse-welded to bare steel. The weld location is beneath the pencil tip.

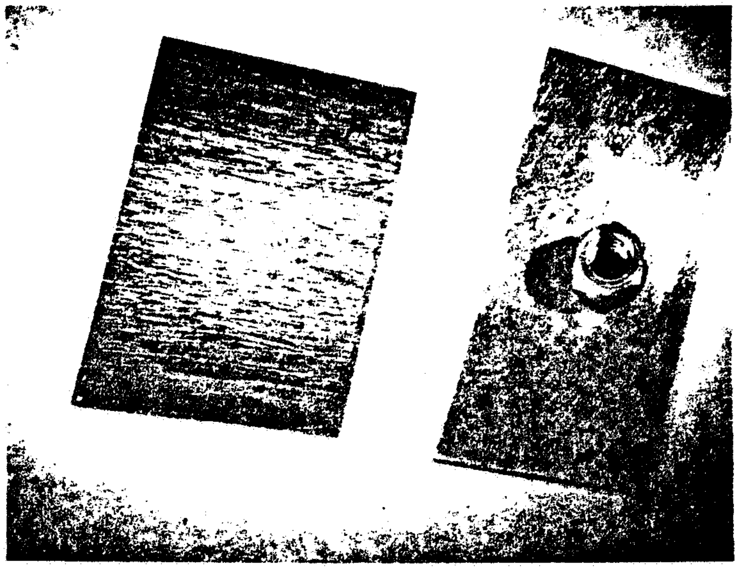

Fig. 8. Photograph of two identical samples showing the ability of Ultrapulse to weld a part (a nut in this case) to the back of vinyl-coated steel sheet.

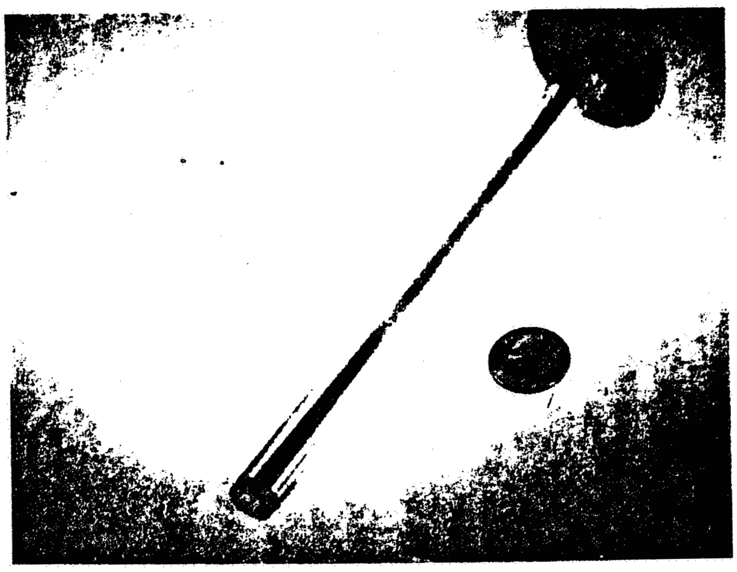

Fig. 9. Photograph of an Ultrapulse-welded exhaust valve. A previously-hardened tip (R_C 50) is welded without tempering the tip wear surface.

Fig. 10. A photomicrograph of the exhaust valve weld above. Magnification is 200X.