Magnetic Pulse Welding for Dissimilar and Similar Materials

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Abstract

The Magnetic Pulse Welding (MPW) process, a cold solid state welding process, is an industrial process, operating at several high volume manufacturing facilities.

MPW is accomplished by the magnetically driven, high velocity, oblique angle, impact of two metal surfaces. At impact, the surfaces (which will always have some level of oxidation) are stripped off and ejected by the closing angle of impact. The surfaces which are then metallurgically pure, are pressed into intimate contact by the magnetic pressure, allowing valence electron sharing and atomic-level bonding. This process has been demonstrated in the joining of tubular configurations of a variety of metals and alloys [1],[2],[3]. Product designers are frequently constrained by the restrictions of traditional joining technologies, which place certain limitations on the type of joint, the materials that can be joined and the quality of the joint. Solid state welding allows manufacturers to significantly improve their product designs and production results by enabling both dissimilar and similar materials to be welded together, thus providing the opportunity to use lighter and stronger material combinations. Magnetic pulse welding is a fast, non-contact and clean solid state welding process. A review of the main elements of the process is presented here along with typical quality testing results and some applications.

Keywords

Magnetic pulse welding, dissimilar metal welding, magnetic pulse systems

1 Introduction

Magnetic pulse technology has been known and applied, for more than five decades [4], mainly in the area of forming and crimping of high conductivity metals, using low frequency pulse generators. Over that period there has been a widening interest in it, not just as an interesting research topic, but also as a well accepted production process. However, only fairly recently has equipment for magnetic pulse welding been developed, that is of a high enough standard to meet the stringent demands required by high volume manufacturers in the automotive and associated industries. Today, this process is used for production in high volume manufacturing and in addition, high frequency pulse generators have been developed, which allow the use of this process for a wider range of industrial applications.

2 Review of Principles

2.1 Process Physical Principles

Figure 1 illustrates the set-up for welding, in which a current (up to 1.3MA for larger machines) is released into the coil, creating an eddy current on the outer surface of a metal tube (outer) placed inside the coil, giving rise to a magnetic field, in addition to that produced around the coil. These magnetic fields oppose one another and cause the outer metal tube to be imploded at high velocity to impact the inner metal tube. If the impact creates the right conditions of angle of impact and velocity, jetting is created and subsequently welding.

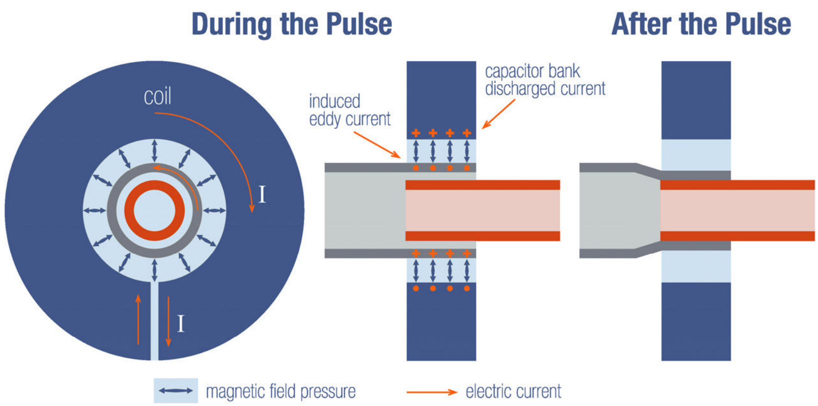

***Figure 1**: Welding Set-up*

Figure 2 show the typical part geometry before and after the welding process. Note that the welded area is always accompanied by deformation of the outer component, as shown in the figures.

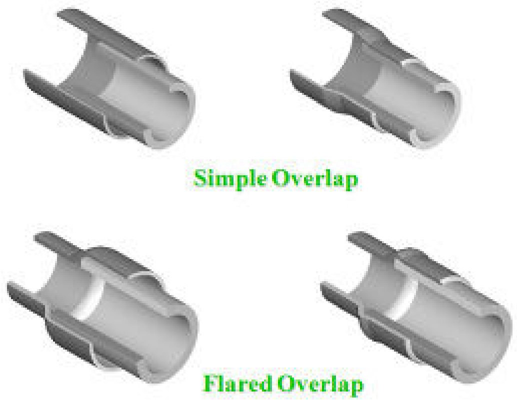

Figure 2a: *Tube weld geometry*

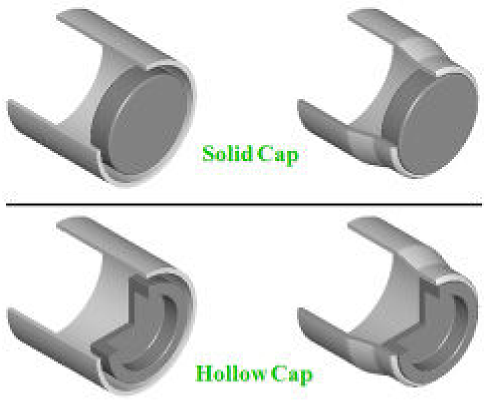

Figure 2b: *Capsule weld geometry*

2.2 The Bonding Mechanism

The detailed mechanism of an MPW weld is a complicated, and a not very widely researched subject. What is commonly known is that, as in explosive welding, a jet is created between the two bonded surfaces by the impact force acting upon them. This jetting action removes all traces of oxides and surface contaminants, allowing the magnetic pressure caused impact to plastically deform the metals for a short instant and to drive the mating surfaces together. This allows the impact of two virgin surfaces, stripped of their oxide layers, to be pressed together under very high pressure, bringing the atoms of each metal into close enough contact with each other, to allow the atomic forces of attraction to come into play. There are a number of explanations for the precise mechanism at the point of collision, but all agree that the metals momentarily behave like liquids, even though they remain solid. Due to the rapidity of the process, temperatures at the interface do not rise significantly. For this reason, it is possible to permanently bond widely dissimilar metals. The quality of the bond at the interface is a product of many parameters, among them the magnetic force, the collision angle, the collision point velocity, and the initial standoff distance between the mating surfaces (see Figure 3). Typically, the pressures at the collision point between the mating surfaces are in the order of 100,000 MPa.

In the graph in Figure 4, defined by Wittman and Deribas [5], jetting and therefore welding is only possible with parameters within the closed area abcdef. Curves 6-6 and 7-7 represent the upper and lower flyer plate velocity limits for welding to occur. A critical collision point velocity related to angle of impact 5-5 defines a curve to the right of which no jetting can occur, while jetting can occur to its left. Abscissae 3-3 and 4-4 define the minimum and maximum angles of incidence in which jetting may occur, while 1-1 and 2-2 respectively define the lowest velocity for which conditions for welding can be created and the velocity above which excessive KE is produced, which will give rise to excessive melting and thus produce unwanted intermetallic alloying. It is obvious that this envelope should be experimentally defined for all metal pairs to be welded. However, negligible work has been reported in this area.

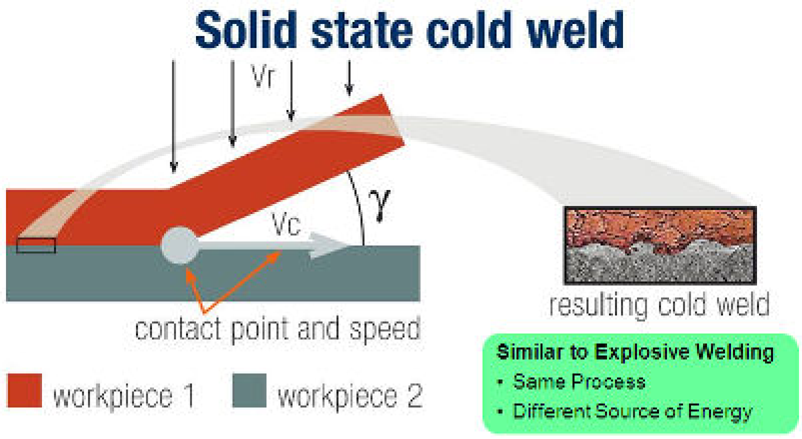

Figure 3: *Main welding variables*

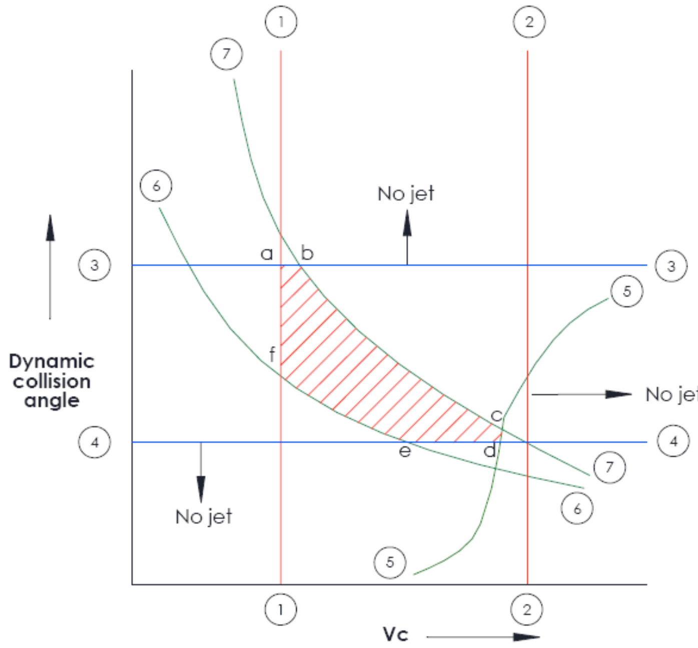

Figure 4: *Jetting envelope for any metal pair*

2.3 Weld Interface Morphology

MPW gives rise to a wavy or waveless interface morphology, where the precise shape is determined by, among others, the properties of the metals, geometries and parameters applied. In the case of similar material pairs being welded, there is no great significance to interface differences. However, in dissimilar metal welding, there is great importance to differences eg interface with intermetallics formed, which may be brittle and reduce the acceptability of the weld. Figures 5-11 show photomicrographs of various similar and dissimilar metal interfaces with well formed waves, while Figure 6 clearly shows the extent plastic deformation that has occurred close to the interface, as a result of the welding process.

Figure 5*: 6082-T6 weld*

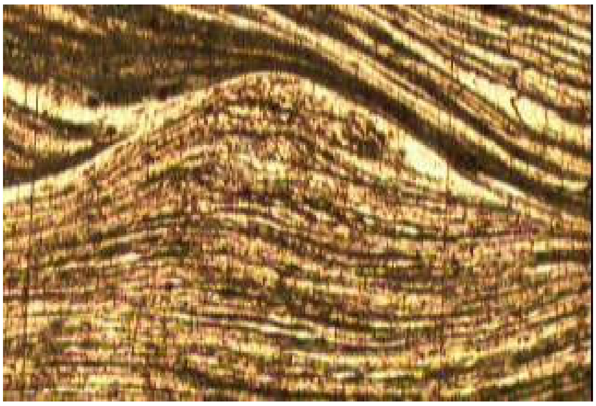

Figure 6*: 7075-T6 weld*

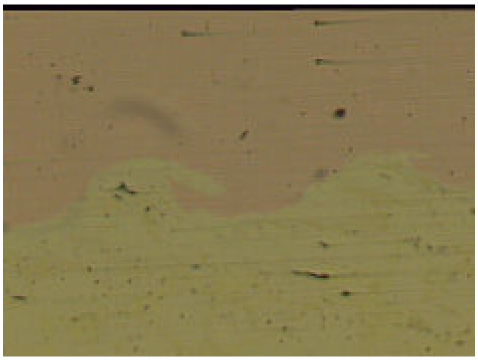

Figure 7*: Cu/Brass 360 weld unetched x100*

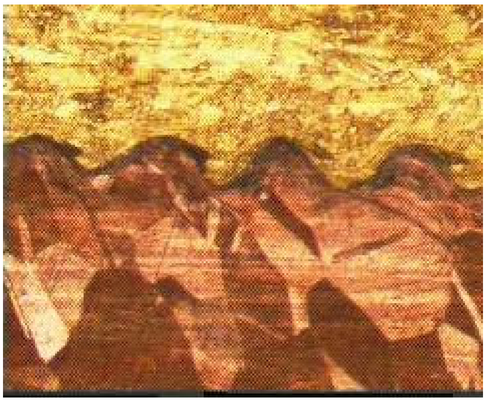

Figure 8*: Cu/Brass 360 weld etched x100*

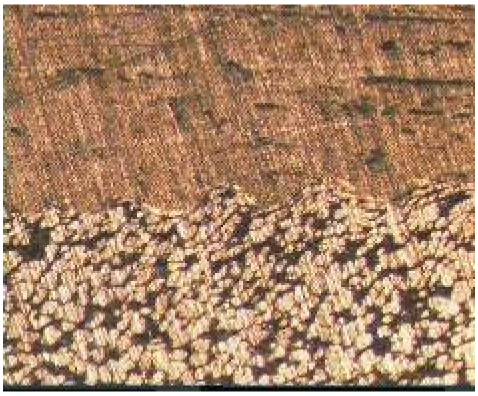

Figure 9*: Al6063 welded to Al casting AlMg5Si2MnRE x50*

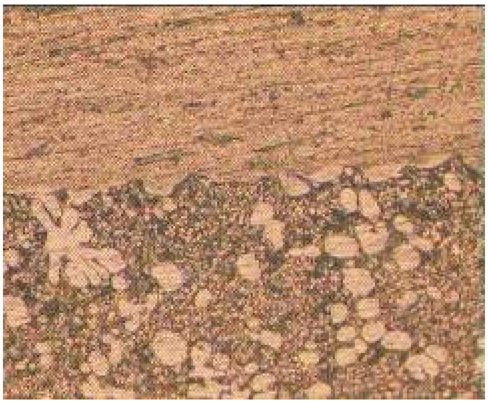

Figure 10*: Al6082 welded to Al casting EN1706 x50*

Figures 9-12 illustrate examples of welds between wrought metals and die cast metals of various Al alloys. This is the first stage in development work being carried out with the end target being cast to cast welds, which in its final stages will also include the welding of magnesium alloys, both wrought and cast.

Figures 12-16 show flat undulating interfaces, the latter two with the assistance of SEM.

***Figure 11**: Al6063 welded to AlMg5Si2MnRE x200*

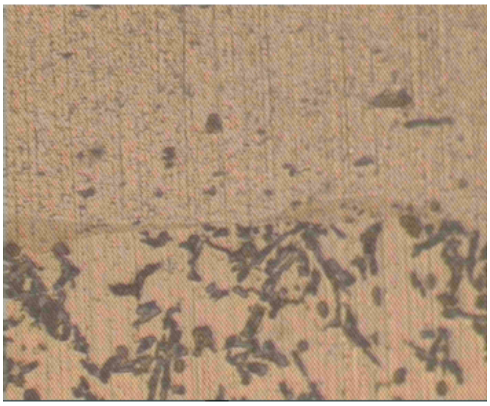

***Figure 12**: Al6082 welded to A380.1 x500*

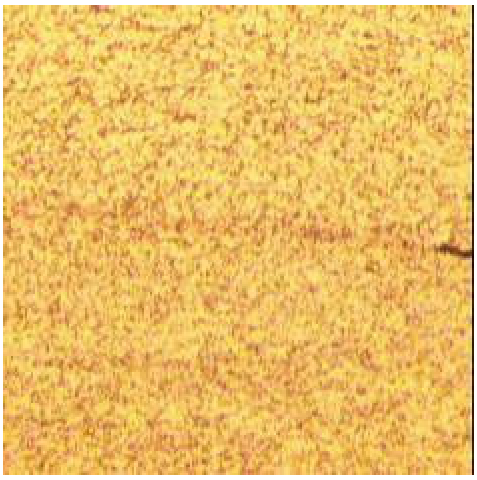

***Figure 13**: Ni200 etched x100*

***Figure 14**: Al/Cu unetched x500*

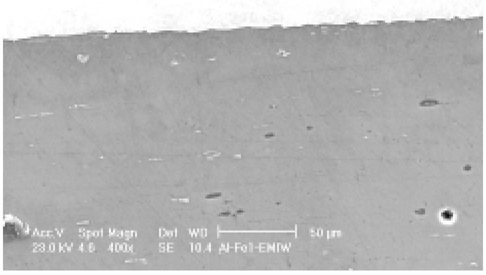

***Figure 15**: SEM Al3003/SS304 x200*

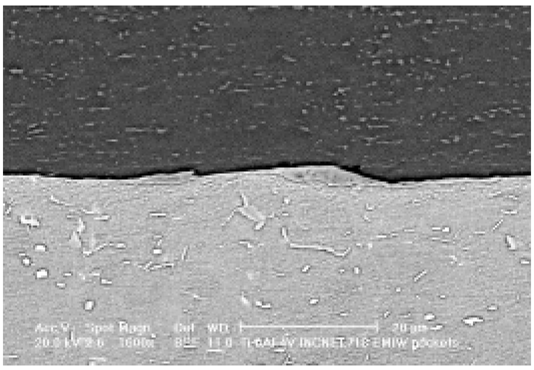

***Figure 16**: SEM Ti6Al4V/Ni Inconel 718x1600*

2.4 Weld Integrity

***Figure 17**: Peel test for Al3003-H12 to SS304*

***Figure 19**: Burst test for Al6061-T6 capsule*

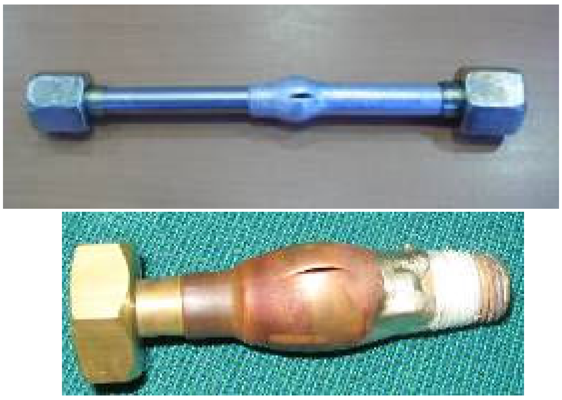

***Figure 18**: Burst test for Al5049 to SS316L and for Cu to Brass*

***Figure 21**: Torsion tested Al/Al 6061-T6 and Al/steel drive*

***Figure 20**: Tensile Test of welded 1020 steel tube*

How does MPW meet international welding specifications. The truth of the matter is that currently there are no tests defined specifically for MPW welds. However, MPW routinely meets all standards for conventional welding, such as leak test, burst test, pressure cycling, etc. In the following are some of the typical test results achieved which will show the level of joint integrity produced by the MPW process. Figure 17 shows a typical peel test of an Al to stainless steel weld, illustrating joint strength. Figures 18 and 19 show burst test results for Al to stainless steel, Cu to brass and Al/Al welds, respectively. It is seen that the weld is not the weak link and failure occurred in the tube base material. Figure 20 shows the ductile failure of a welded steel tube, failure occurring remote from the weld, while Figures 21 illustrates torsion test results for both Al/Al and Al/steel joints, in which the weakest point is the tubeshaft and not the weld.

Typical results for helium leak test (see later Figure 29) show that the process is capable of producing hermetic seals. Routinely welded parts are required to meet a level of 5g/year at 30 bar R134a (automotive specification). Tests were carried out using a mass spectrometer and the results show 64-150 times better than the specification, as illustrated in Table 1.

Sample n° 61 = 3.9 E - 7 mbar at 30.3 bar = 0,072 g / y
Sample n° 62 = 3.3 E - 7 mbar at 30.4 bar = 0,061 g / y
Sample n° 70 = 3.2 E - 7 mbar at 30.3 bar = 0,059 g / y
Sample n° 80 = 1.8 E - 7 mbar at 30.3 bar = 0,033 g / y
Sample n° 81 = 3.9 E - 7 mbar at 30.3 bar = 0,072 g / y
Sample n° 82 = 4.2 E - 7 mbar at 30.3 bar = 0,078 g / y

***Table 1**: Helium Leak Test Results*

Testing the same item in a pressure cycling test at 1-30 bar, 1.25 Hz, with hydraulic oil at 80 deg C, gave good results after 155k cycles, when subsequently tested in water with 30 bar N_2 gas for 5 minutes.

2.5 Weld Applications

Figure 22 shows the layout of the typical system. An AC power source is transformed into DC current, which energises a bank of HV capacitors.

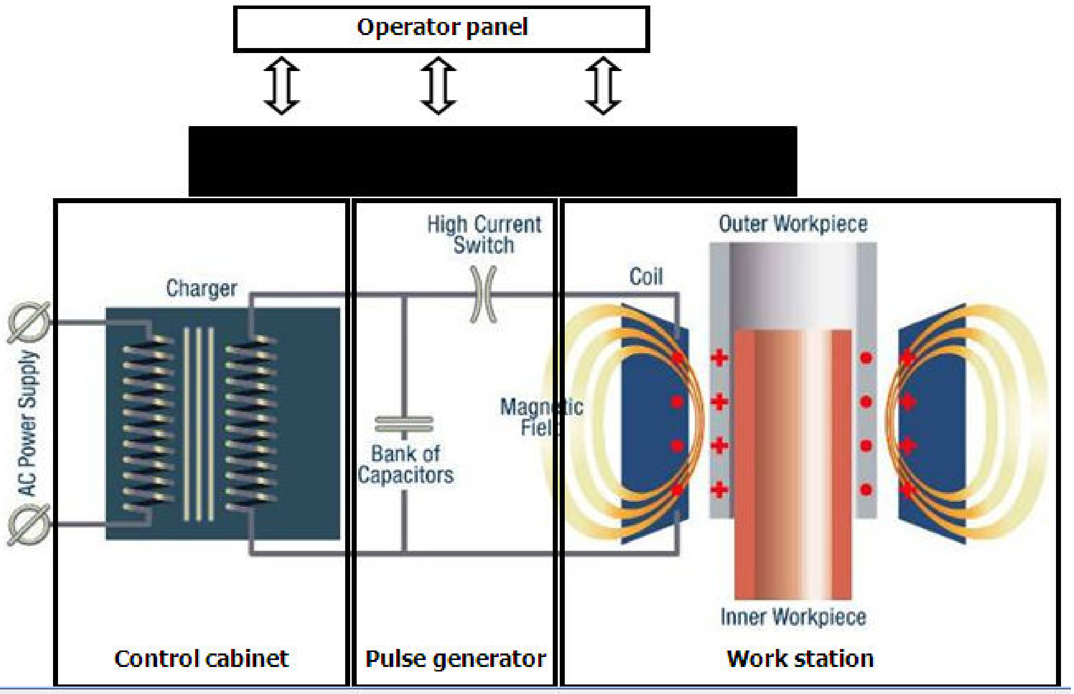

***Figure 22**: Magnetic pulse system principles*

The overall system is shown in Figure 23. It consists of a pulse generator, a control cabinet, a work station and an operator panel for remote operation of the process.

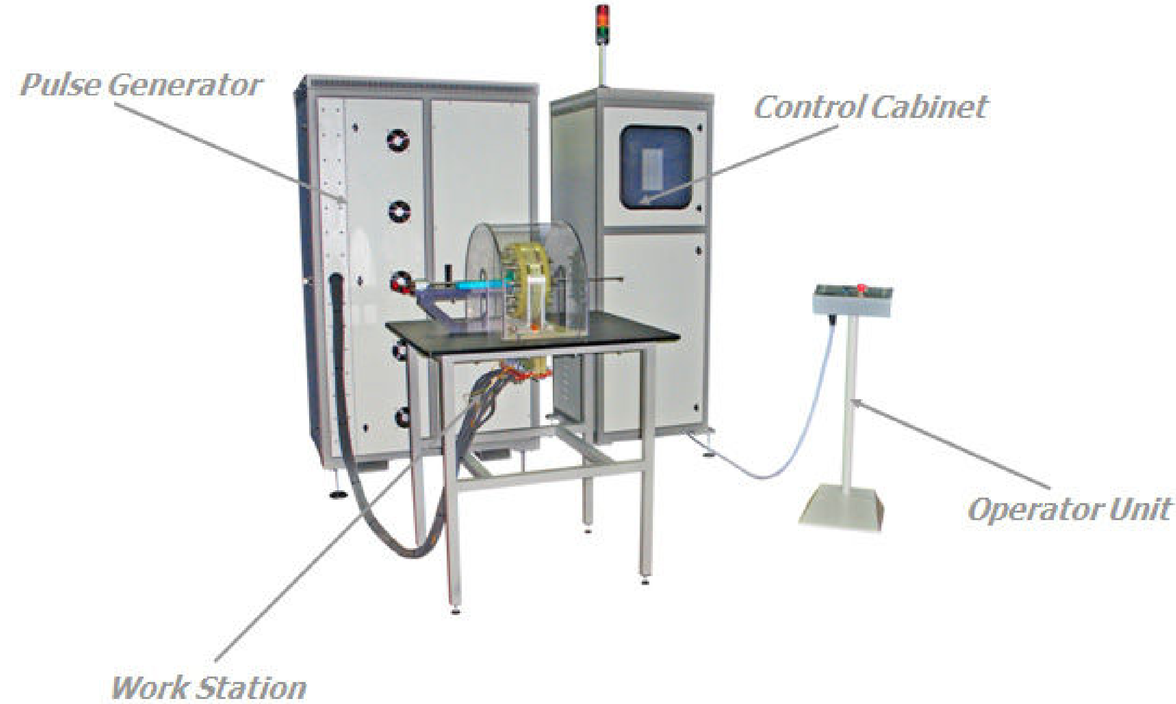

***Figure 23**: The MP System Components*

The pulse generator consists of an electrical storage module, grounding block contactor, a cooling system and a cable connector. The control cabinet consists of a 3-phase line, fuses and circuit breakers, high voltage transformers, AC to DC transformation circuits.

A typical low energy machine of 10kJ/9kV is shown opposite. This has all the components mentioned above, consolidated in a single unit, including the coil assembly being mounted directly on the machine.

***Figure 24**: Low energy pulse generator*

3 Summary

MPW is a "green" solid state welding process producing high speed versatile, high integrity weld joints, some of which, from Figs 25-30, have been incorporated in large series industrial production. The weld produced is a cold weld, stronger than the weaker of the metal pair, good for dissimilar as well as similar metals and conventionally unweldable metals, heat treat characteristics always being preserved.

Figure 25: *Al fuel filter*

Figure 26:*Al/steel driveshaft*

Figure 27: *Al/SS earth connector*

Figure 28: *Cu/brass welds and Al/steel welds*

Figure 29: *Al fuel filter and A/C receiver dryer*

Figure 30: *Al7075-T6 high pressure capsule*

References

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