

Miyachi Europe GmbH

Lindberghstrasse 1
DE-82178 Puchheim

Tel.: +49 89 839403 0
Fax: +49 89 839403 10
E-mail: contact@mec.miyachi.com
www.miyachieurope.com

Author: Jörg Kundrat – Vice President of development, production and technical customer service

Date: June 2011

Resistance Welding Applications in Connector Technology

Summary

Resistance welding is a robust method with a wide range of industrial applications. It is a bonding technique which can be used to procedure heavy-duty coalescence bonds for plug-in connector technology. The process of resistance welding can be easily managed using modern control technology. Current technological standards provide a multitude of possibilities for process monitoring and analysis as well as rapid cycle times.

1. Introduction

The increasing use of heavy-duty connectors and components, in motor vehicles in particular, has led to a rise in the use of bonding methods not previously employed or only rarely employed [1]. Until recently, soldering and crimping were the methods most frequently used. Today, these procedures are reaching the limits of their useful application due to the steady increase in levels of power density in modern equipment. Soft-soldered joints are reliable up to temperatures of approx. 125°C. Crimp joints are susceptible to fatigue caused by increasing contact resistance throughout their service life.

The same applies to numerous electronic devices. Levels of functional density in, for example, portable equipment are increasing while sizes and weights are simultaneously falling.

In light of these developments, bonding methods which produce joints which fulfil the following requirements have been used ever more frequently during the last few years:

- low electrical resistance,
- high temperature resistance,
- high mechanical strength,
- good corrosion resistance.

These properties may only deviate within tight margins of tolerance during the entire life span of the product. Resistance welding meets these requirements perfectly.

2. Materials and cross section areas

Inevitably, the demands made on cable and connector components greatly restrict the choice of materials which can be employed. Copper or copper base alloys are the first choice. In many cases they represent a good compromise between high electric conductivity and sufficient mechanical stability. The electrical conductivity ($\lambda_{el.}$) of technical grade copper (e.g. E-Cu58) is around 58 mS/m. E-Cu58 is, therefore, the second most efficient electrical conductor, surpassed only by silver which has a conductivity of 62 mS/m.

Cable cross-sections of 0.14 mm to 100 mm² can be reliably connected using resistance welding. As a rule, resistance brazing is used for very large cross-sections where space is restricted. During brazing, filler material in the form of a section of solder strip is placed between the parts to be connected. Resistance heating is then applied to produce hard soldered joints with very high toughness and minimal component deformation. Surface activation of the bonded parts is also guaranteed by the filler material.

3. Systems engineering and process control

Resistance welding - a 3-dimensional process

Resistance welding is a production process described by 3 dimensions; electrical, mechanical and temporal. The fourth dimension is formed by the material. However, to date, welding systems have no influence on this factor. This means that the dynamic stability of the individual electric and mechanical process parameters is critical to the repeatability of the process. Uncontrolled electrical and mechanical vibration during the process alters the generation and conduction of heat. For this reason, vibration should either be eliminated using process control or, at the very least, detected using monitoring.

Active control of the mechanical axis during the welding process

The electrical dimension is only relevant for as long as the welding current is maintained. In contrast, mechanical parameters influence the quality of the joint before, during and after application of the welding current. They influence the contact conditions responsible for the generation and dissipation of heat. In the first step of the process, the welding electrodes must perpetually bond the components together as quickly as possible to create repeatable electric and thermal conditions. Initial deformation is considerable after the welding force has been applied, particularly for the soft materials which are predominantly used. The welding current is then released which leads to a mechanical "interference pulse". If the mechanical system then vibrates due to unfavourable spring-mass relationships, repeatable process starting conditions may be adversely affected. The electromechanical influence of the welding current can also cause vibrations in the electrode system. In the last process step, the electrodes are retracted. Hold time influences the speed at which joined components cool and, therefore, also affects the metallurgical properties of the joint. It is obvious that rapid, controlled devices have incontestable advantages over passive, uncontrolled welding systems in all stages of the process. This is especially true if we consider the rapid processing times which can be achieved due to quick indirect cooling of the components. Some of the latest developments which have proven highly effective in practice [2, 3] are inverter power supplies for the rapid adjustment of electric parameters and electric servo welding pincers (**Fig. 1**) used as rigid, active mechanical axes.



Fig. 1: Servo welding pincer.

Process monitoring and evaluation

Process analysis and process monitoring play a particularly important role in quality assessment of bonds in connector technology as every faulty weld could potentially cause the complete failure of an entire assembly.

During evaluation, at least one variable process parameter is monitored for each process dimension. Heat input is ensured by monitoring electric parameters such as current, voltage and derived quantities. Welding force is a mechanical process parameter which describes thermal and electric bonding. The difference between heat input and heat dissipation at the weld is indirectly derived from the penetration value and constitutes complete process monitoring for dynamic repeatability.

Graphic evaluation and analysis

Various graphic displays of process parameters provide detailed information:

- dynamic process waveform (individual process evaluation) (**Fig. 2**),
- progress display SPC run chart (trend) (**Fig. 3**),
- histogram (stability, analysis of systematic errors) (**Fig. 4**).

For example penetration processes which have progressed too far can be detected as accelerated movements during the welding process and the profile of the welding current suitably adjusted. Similarly, secondary maxima in the normal distribution of energy can indicate a disruptive bypass at the weld. It is also very useful to be able to recognise visible variations in the process parameters displayed in the SPC run chart. This allows corrective measures to be initiated in good time before defective parts are manufactured.

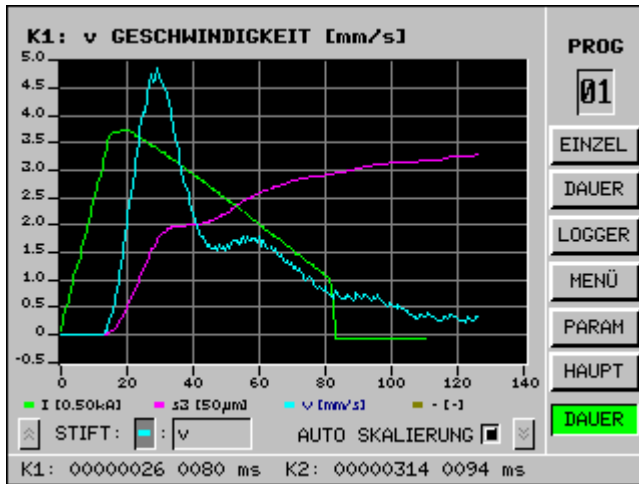


Fig. 2: Waveforms.

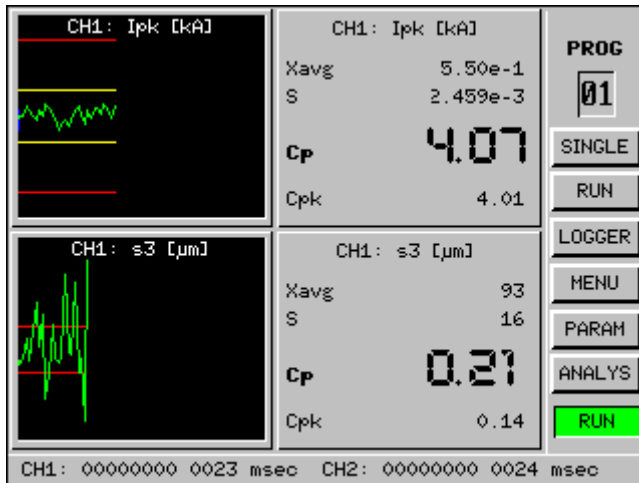


Fig. 3: SPC run chart.

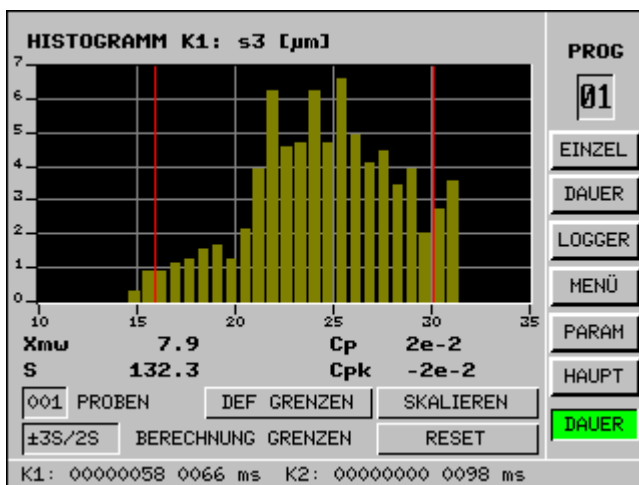


Fig. 4: Histogram.

Static and dynamic process monitoring

In process monitoring, a distinction is made between static and dynamic monitoring. Static monitoring compares measured numeric process parameters with the set limits. In contrast, dynamic monitoring compares each individual point of a waveform. This envelope waveform monitoring therefore constitutes a combination of quantitative and qualitative monitoring. The main objective is to find and mark parts whose process parameters display undesirable vibration or variation during the short process and which therefore do not correspond to the defined process waveform (Fig. 5).

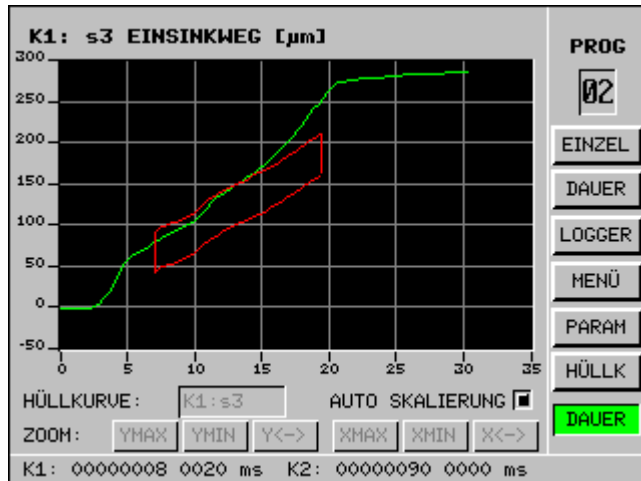


Fig. 5: Faulty weld – path outside of envelope.

Adaptive process control

Electric and mechanical parameters can be regulated to comply with certain desired curves. In addition, controls which react when set default values are reached can also be very useful. This may involve either changing or stopping a process sequence when a certain value is reached. The recent development of "path-dependent power cut-off" has boosted quality considerably. The latest adaptive controls, such as APC, aim to stabilise the initial conditions of the process [4] and thus significantly increase process stability.

4. Applications

In the field of connector technology, the demand for long product service life is continually increasing. In addition, products are required to occupy as little installation space as possible whilst retaining the same integration levels. These higher performance densities lead directly to an increase in temperature.

Depending on the function of the device, contact points must be designed accordingly to suit widely differing conditions. In general, 5 different combinations can be implemented using resistance welding (Fig. 6).

Connection combinations

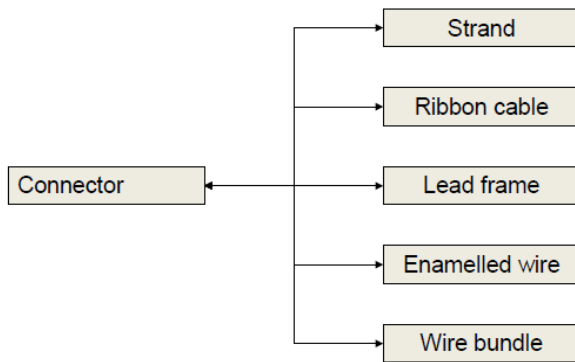


Fig. 6: Combination options for connections.

The main application for connector technology must surely be connecting strands to connectors. The problem with this connection is the geometric positioning and fixation of the strand within the joint connection. The resistance welding process provides different possible solutions to this problem. Firstly, it is possible to position the strand in a moulded part in a similar manner to crimping. Additional connection elements are usually dispensed with due to the commonly prioritised requirement for compact design. In this case, a device for compacting separate wires (**Fig. 7**) carries out the positioning and fixing of the strand during the process. The compressed strand can subsequently be welded as a fixed component with clear geometry in a single step (**Fig. 8**). If geometric conditions allow, it is also possible to weld the single wire strands directly to the connector in a single step using a compacting device of this kind. For small series production at manual work stations, strands can also be positioned in specially moulded welding electrodes. The strand is then compacted and simultaneously welded onto the connector during the process (**Fig. 9**).



Fig. 7: Compacted strand.

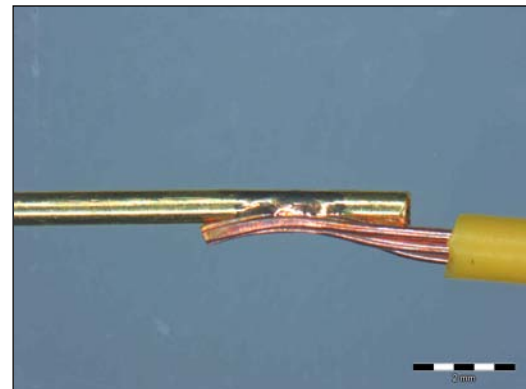


Fig. 8: Compacted strand on connector pin.

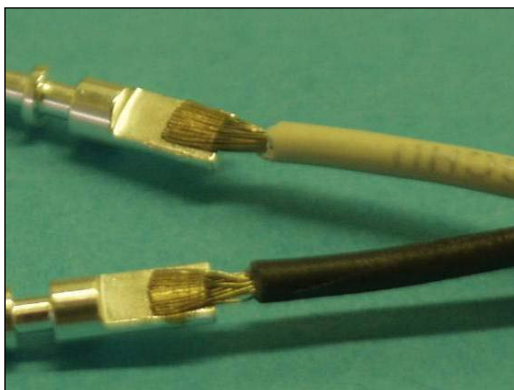


Fig. 9: Strand on connector using moulded electrodes.

Further options for connector combinations include connectors on ribbon cable (**Fig. 10**) and on lead frames (**Fig. 11**). If the cables being connected are insulated copper wires, they can be stripped and welded in one step using resistance welding [5]. This method is used for electrical bonding of phase outputs in electric motors and coils and to attach HF strands to connectors (**Fig. 12**).

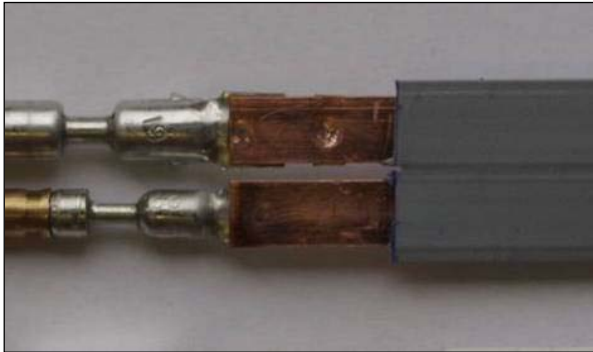


Fig. 10: Ribbon cable on connector.



Fig. 11: Lead frame on connector.



Fig. 12: HF strand on connector.

5. Technical process differences between crimping and resistance welding bonding methods

Joints produced by crimping and resistance welding bonding methods differ mainly in the type of electric contact used. In resistance welding, coalescence is created by a diffusion welded joint which eliminates contact resistance (**Fig. 13**). In contrast, when using the crimping technique, a connecting element is used to create contact pressure on the strands which ensures electrical contact via the contact resistance (**Fig. 14**).

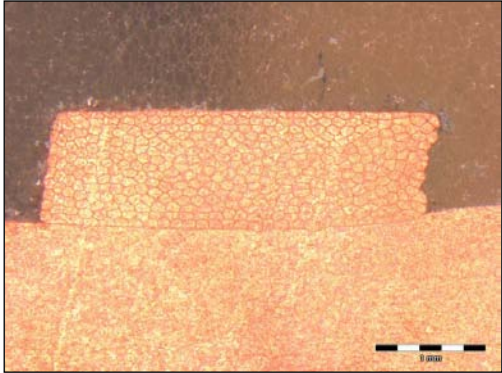


Fig. 13: Strands compacted on connector - microsection.

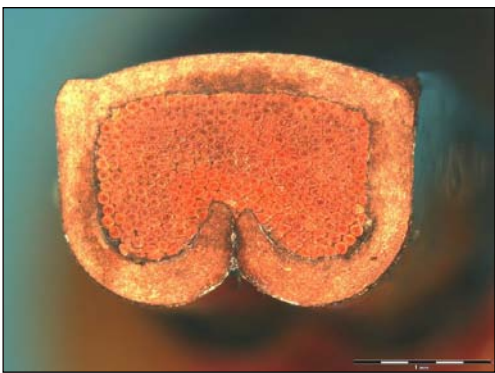


Fig. 14: Strands crimped on connector - microsection.

Coalescences created using resistance welding are superior. On the other hand, crimp bonds can be manufactured using much less complex processes. Crimp bonds are deformation joints. This means that only the dynamic mechanical process variables are relevant for the crimping process. In contrast, resistance welding is affected both by dynamic mechanical process variables and the dynamic electrical process variables responsible for resistance heating. Resistance welding therefore inevitably makes greater demands on system technology but can also achieve cycle times of less than 0.5 s, depending on execution.

6. Summary

Resistance welding can be employed to produce high-quality bonds without additional connector elements for a wide range of connector compatibility.

These bonds are characterised by:

- high allowable performance density,
- long service life,
- compact installation space,
- wide range of safe operating temperatures,
- employment in aggressive environments.

References

- [1] Schmitz G. and Lindner, K.: Mikrofügetechnik – Stand und Ausblick. DVS-Berichte Volume 225, P. 1. Düsseldorf 2003
- [2] Greitmann, M., Volz, O., Stamm, R., Kundrat, J., Böhmert, E. and Mittler, B.: Untersuchung zur Eignung von piezoelektrischen Aktoren als Nachsetzelemente für die Widerstandsschweißtechnik. Schweißen und Schneiden, 53 (1), P.10-19. Düsseldorf 2001.
- [3] Schmid-Dörnte, J., Kundrat, J. and Böhmert, E.: Der Servoschweißkopf – Dynamik im Schweißprozess, Regelbarkeit der Servoantriebes. DVS-Berichte Volume 189, P. 127-130. Düsseldorf 1998
- [4] Putting Active Part Conditioner (APC) to Work. Unitek newsletter, Volume 4/No.2. Monrovia, CA 2001.
- [5] DVS Merkblatt 2921: Widerstandsschweißen von lackisolierten Drähten. DVS-Verlag. Düsseldorf 2007.

Miyachi Europe GmbH

Lindberghstrasse 1
DE-82178 Puchheim

Tel.: +49 89 839403 0
Fax: +49 89 839403 10
E-mail: contact@mec.miyachi.com
www.miyachieurope.com

