Resistance Welding Of Small Parts

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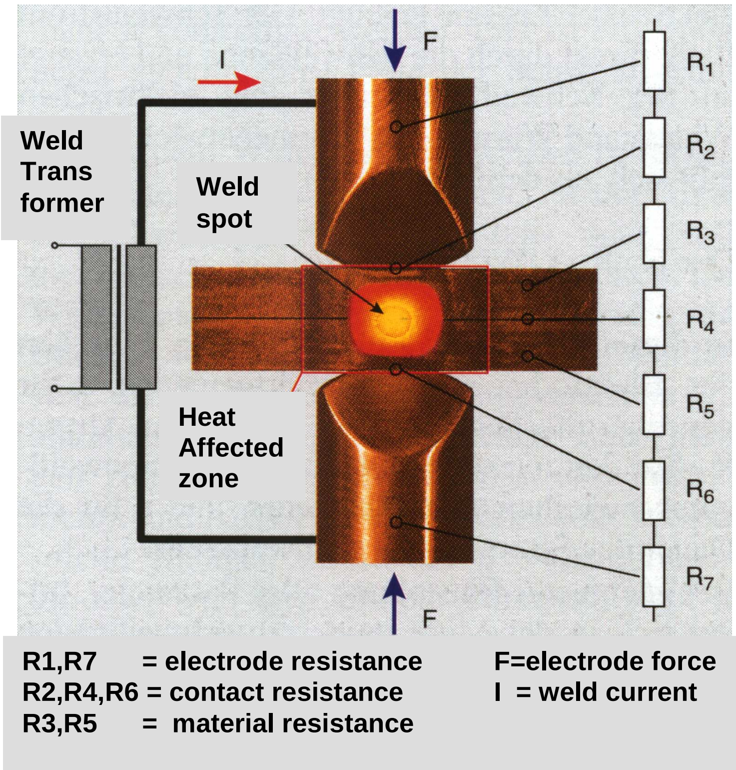
1. Foreword

This manual shall support the machine operator and set-up person, explain the physical principles and thereby train the understanding of the welding process to enable the person to better recognize problems and to remedy the causes for these problems.
Chapters 10-12 also illustrate engineering and process considerations affecting the machine operators for possible optimization processes, but also addressing the engineers directly. The practical construction and design of the welding area already during planning can help decide on the process capability and reject rate.

2. Introduction to the basics

2.1 The electrical resistances as relevant variables

As the name “Resistance welding technology” already indicates, this is primarily about the electrical resistances of the parts as well as the contact resistances.
These electrical resistances together with the set current generate so much heat that the material becomes liquid and bonds together.



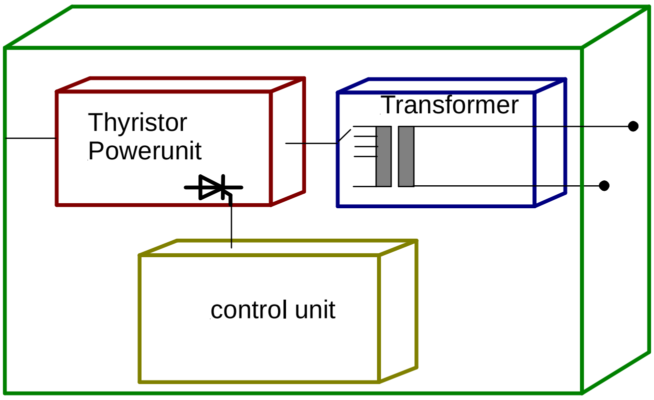
(Fig. 1) Resistance behaviour and spot weld

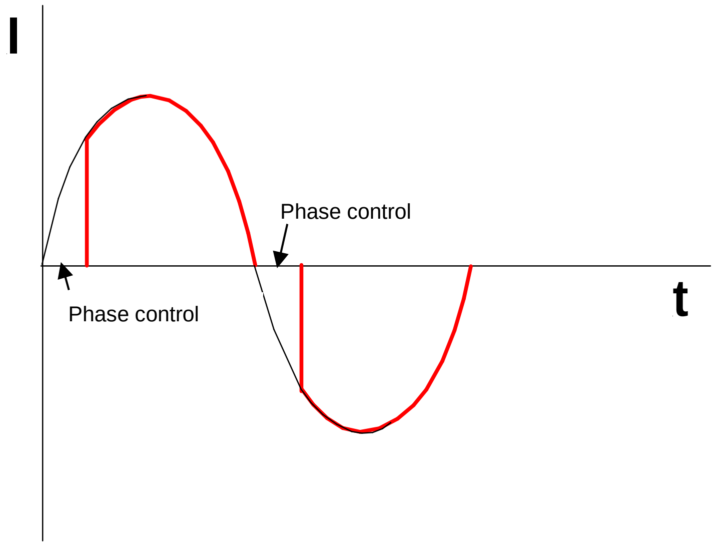
Figure 1 demonstrates the number of resistances existing in the welding area. On the one hand, these are the temperature-dependent material resistances (R1, R3, R5, R7) and on the other hand, the contact resistances (R2, R4, R6).
The objective is to generate the heat and thereby the weld spot between the parts to be bonded and to keep them constant during the entire batch process.
The weld spots always develop where the average resistance is greatest; the constancy for the batch process can then be maintained if the resistance can also be kept consistent. This must therefore have the highest priority for the welding process.
In the reverse, this means: If a weld joint suddenly no longer has the same quality, this is generally not due to the welding machine but a change of the resistance network, which finally causes the weld spot to be no longer between the parts to be joined.
In this manual we will explain the problems arising in the application and the means that are available to counteracting them. In the end, the interaction of a good construction/design of the welding area and a series process matters in not changing the existing resistances, or only to a small degree.

2.2 Different methods of power generation

2.2.1 Alternating current source

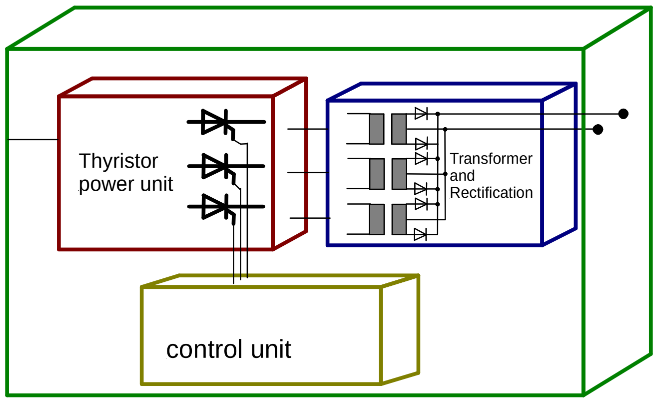
Alternating current controls for single-phase mains connections marked the beginnings of resistance welding technology. Even nowadays there is still a strong demand for resistance welding machines with alternating current technology.
These controls work synchronously with the mains and take the energy directly from the mains. The mains must therefore be well regulated and able to supply the energy.
The power settings are made, on the one side, through fine gradation of the secondary voltage, on the other side, infinitely variable through phase control.
The application includes uncomplicated easy to weld parts that do not require the exact regulation of the welding energy; these are parts normally requiring very long weld times.

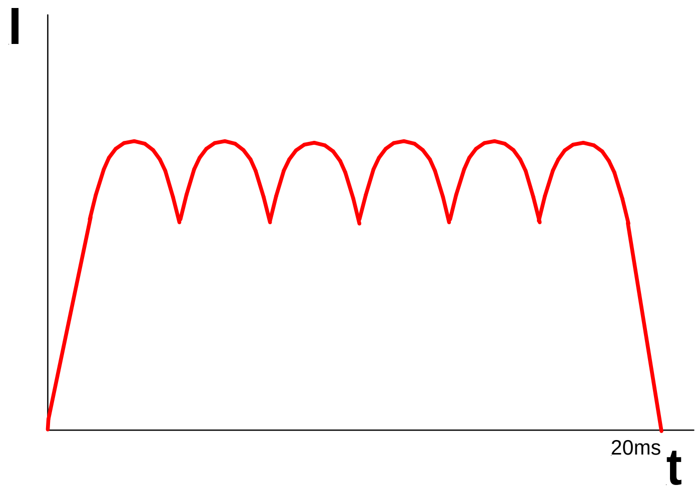




2.2.2 Three-phase rectification

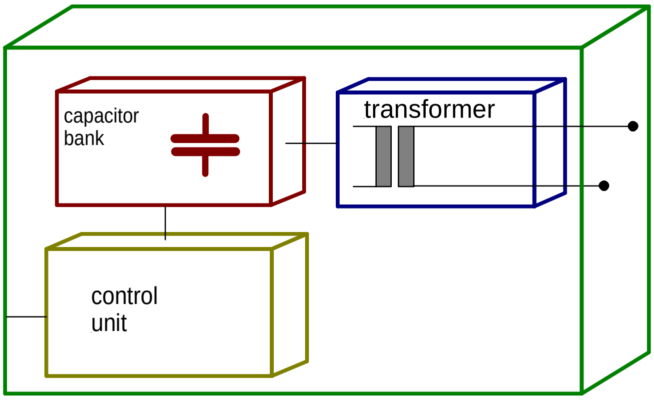
The three-phase secondary rectification compared with alternating current already has the advantage of polarity and a continuous welding pulse without a pause. Regulation merely occurs through the length and amplitude of the weld pulse; the rise time is specified. Used also for simple welding tasks.

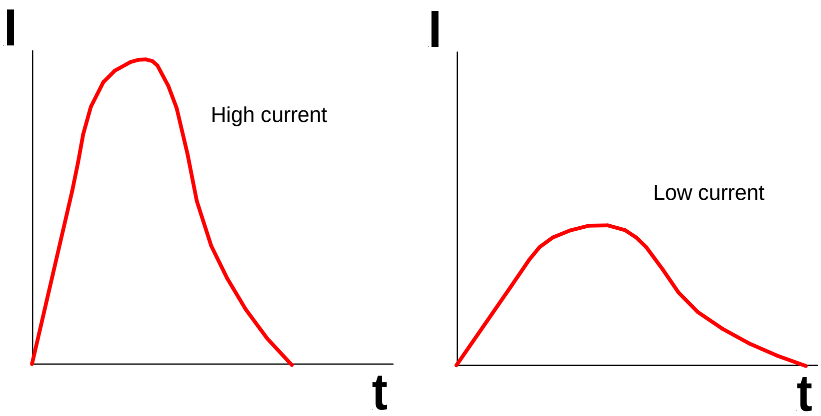




2.2.3 Capacitor discharge

The low power consumption from the mains constitutes the advantage of control systems with capacitor discharge technology. A capacitor battery is charged over an extended period with a low current from the mains supply to an adjustable stabilised voltage, which is independent from the mains voltage. When the welding process is triggered, the electrical energy stored in this manner is released to the work piece via a transformer during an extremely short span of a few milliseconds and with a very high current amplitude.
The drawback is the severely restricted regulating capability of the current.
The curve progression is predefined by the capacitor discharge curve and only the amplitude of its current can be adjusted.

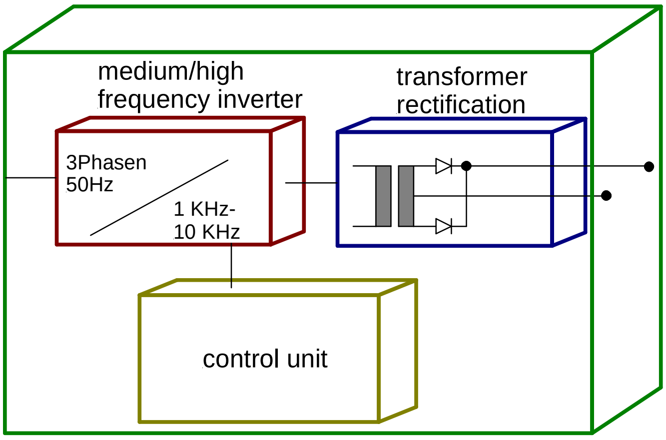




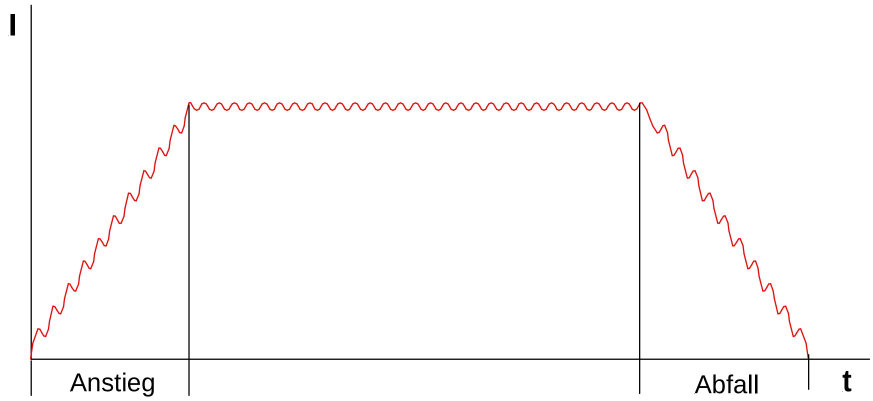
Short pulse Long pulse

2.2.4 Medium/high frequency

The medium/high frequency inverter technology in its control behaviour resembles that of the regulated direct current most closely, however, its rise time is still restricted and depends on the frequency. Another disadvantage is the residual ripple over the entire weld pulse.
Its benefit lies in the fact that through the high frequency technology the power components are much smaller than those for direct current regulation with semiconductors.



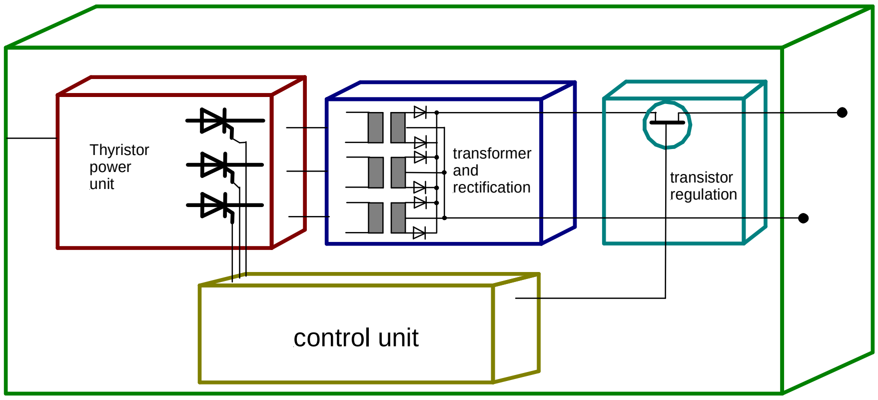
Function principle of medium frequency inverters

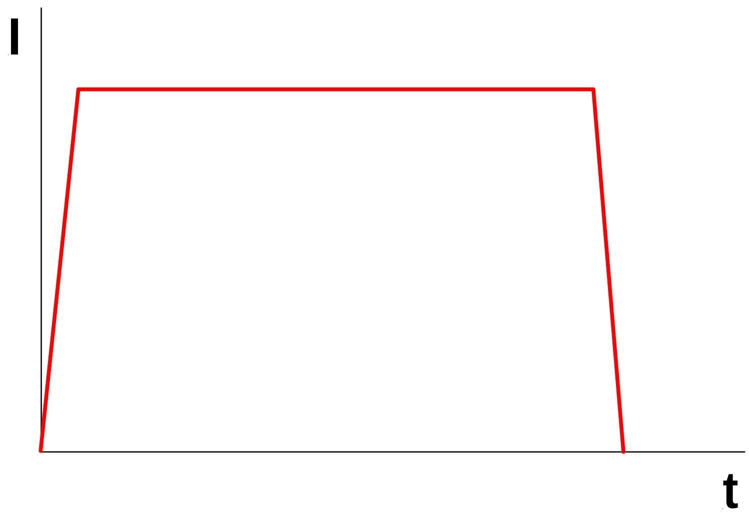


Weld pulse at medium frequency

2.2.5 Transistor regulated direct current

With transistor-controlled direct current machines, switching and control of the weld pulse do not occur on the primary side with phase control through thyristors but on the secondary side via transistors behind the rectifier diodes. The highest possible switching output and the power loss to be carried off limit the output power.
Smallest losses and optimal controllability predestine the regulated direct current technology also as solution for so far insurmountable joining tasks. The complexity of the weld pulse can be adjusted as desired. Rise times from 1 ms to a final current of 20 kA can be realised. This flexibility of the adjustable current progressions allows the process to be superbly adjusted to the resistance structure of the welding tasks.





2.3 Secondary/primary regulation and their differences

The difference between primary or secondary regulation relates to the position where the information required for the electrical control behaviour is queried. The decisive difference lies in the fact that with primary regulation the transformer is included in the control loop thus making the entire control behaviour much more sluggish. A secondary regulation is therefore essential for quick control behaviour.
The additional distinction needs to be made for secondary regulation whether this is transistor-controlled constant current control or inverter current technology. Transistor-controlled constant current control provides an even more exact control behaviour than inverter current technology, since the necessary transistors – exactly regulating the desired current – are located here between the welding parts and the transformer.
If a quick cut-off of the current is therefore desired with an inverter power source, the entire residual energy still stored in the transformer enters the welding parts while with transistor control this residual energy is converted to heat. This energy does not then reach the welding part. The parts and the electrodes are thus protected in the event of a desired quick cut-off of the weld pulse.

3 Parameter changes and their effect

The following statements refer to normal spot welding with copper materials. Other principles may apply with different materials or welding tasks (HotStaking or compacting). However, the basic principle is the same. In the end, one must always consider the effects a parameter change has on the resistance behaviour or the heat properties in the bond.

3.1 Current regulation, voltage regulation, power regulation

In new control generations the user can select the variable constantly to be regulated constantly. In general, current regulation leads to the most constant results in regard to the series process since changes in the supply lines and additional voltage drops have the least impact on the result and the quality assessment.
Voltage or power regulation is used primarily when materials have significantly fluctuating temperature-dependent material resistances, which, with liquid material, leads to an actual explosion of the parts. This is not the case with copper materials.

3.2 Pressure

By changing the pressure for the welding process, all contact resistances are affected. This means: The higher the pressure the better the contact between the parts. The contact resistance then becomes smaller at higher pressures. The welding result is therefore weaker at lower contact resistance and constant current.
The higher the pressure, the weaker the weld.
The lower the pressure, the stronger the weld.

For the welding process we need to create a weld spot exactly between the parts to be joined and this is best reached when resistance R4 is greatest.

The object should be then to weld with as little pressure as possible; the R4 is then very large. Another reason for pressures are the weld bolds and ridges (see chapter 10), which are shaped back at high pressures without being able to play out their advantage.
However, when the pressure becomes too small, we run into the problem of the welding process having too high a splattering tendency. This is primarily a problem of the weld heads (see chapter 5 Follow-up behaviour).
Another problem with too little pressure is the partial alloying of the welding parts to the electrode (bonding tendency). This phenomenon can best be explained by too large a contact resistance between the electrode and the part. This finally leads to the fact that the parts also wants to bond with the electrode.

3.3 Control variable

The control variable (current, voltage, output) should be chosen slightly lower at the beginning, depending on the set control behaviour. The ideal result is then gradually approached from below in the course of the trials. The principles are relatively simple here: The higher the value is set, the stronger the weld.

3.4 Time / Pulse

The set times are divided into a rise time, a weld time, a fall time and a pause. Depending on the control system, this can be repeated several times and a complex curve progression is thus created (preheating/closing of the weld piece and a second, much higher weld pulse).
The most important times are the rise and weld times.
The weld time and the amount of the control variable determine the entire energy to be used to change the parts to the liquid condition.
The rise time determines how fast the entire process shall be run. Principally, a welding process should be carried out as high (control variable) and as quickly as possible. For this the rise time must preferably be short to achieve the desired current (voltage, output) as quickly as possible and the higher contact resistances between the parts are utilized as long as they are still available.
The maximum achievable speed, in turn, depends on the follow-up behaviour (see chapter 5).
Too short a rise time always creates an increased tendency to splattering.
A very long weld time increases the problem of partial alloying with CuFe materials.
With the pause times we determine who long the electrodes still remain closed after the welding process; we must allow time to the parts for the liquid material to become solid again.
In this manner, we also draw much more heat from the parts into the cooled down electrodes, thereby preserving the environment of the weld spots.
The fall time is only relevant in combination with several pulses.

3.5 Cut-off type time or depth

In the normal situation the weld pulse is carried out as programmed with the individual weld times. However, in some situations it makes sense to terminate the current pulse immediately after a certain welding depth has been reached since it can be assumed with this welding depth that the welding result is good. This cut-off version is used wherever different contact resistances can be expected between the welding parts due to tolerances and surface contaminations in the batch production process. In this manner, relatively good process capabilities can be achieved in spite of the poor basic conditions.

3.6 Monitoring

Several parameters are monitored for the quality assessment during the welding process, for which upper and lower limits are entered. These thresholds then allow making a quality statement on the weld.
Both the weld depth and the final value achieved are monitored, together with the entire curve progression, the voltage (with current regulation) as maximum value and effective value (analogous with other control types). In case of the cut-off type “depth”, the weld time is also monitored.

4 Polarity

When welding with a direct current source, the side of the material connected with the positive pole of the current source becomes warmer.
This phenomenon occurs only when welding different materials and thereby moves the weld spot in the direction of the positive pole of the current source. The effect is generally referred to as Peltier effect.

5 Follow-up behaviour

Follow-up behaviour is the property how fast the mechanical weld heads are able to carry out a closing movement or in how far they are hindered in carrying out this closing movement, e.g. through friction or masses to be moved.
During the welding process, the parts become liquid in a matter of milliseconds and diffuse into each other. Depending on the welding application, distances up to 500 µ are covered. This means that within this period the electrode may never loose contact to the part. Thus, the minimum possible pressure and the minimum possible rise time of the control variable is determined by the mechanical aspects and especially the follow-up behaviour and the masses. The weld heads should therefore be arranged in a spring-cushioned manner to allow this spring action to follow up on immediately developing distances with low masses.

6 Materials and surfaces

6.1 Materials

Constantly more exact control behaviours and control criteria make the welding of more and more new materials possible, which in the past were considered impossible or difficult to weld. However, to realise a process ready for batch production, more or less requirements and incidentals must be fulfilled – depending on the choice of materials – making economic manufacturing even possible.
Because of the use in electronics, copper materials have become increasingly dominant during the past years; they can be welded in almost any alloy.
There are other materials, though, such as titanium, steel, nickel silver or sintered carbide that can be welded.
To scrutinize the welding capability of your material combinations and the correct basic conditions for a production-ready solution, we ask you to contact us already in the design phase of your projects, if at all possible. At this time we will be able to implement the entire engineering design into a production-ready welding task without the cost factor involved. We will be glad to make our experience available to you in determining the correct welding parameters for the series start.

6.2 Surface finishing

Surface finishing is extremely important for the quality and process capability of the weld. By applying surface finishes with tin, silver or gold, poor properties of the materials for the welding process (oxide) or impurities of the surfaces can be corrected to ensure process capability. The important point is that the melting temperature of the surface finishes is lower than that of the base material.
If this is not the case, the additional layer acts as a separating layer between the welding materials preventing any diffusion of the materials into each other.
Any form of passivation or theolenes should be done without as much as possible since these sulphuric bonds cause fouling of the electrodes thus having a very negative impact on the process capability). (Theolenes and passivations are used as tarnish protection, e.g. of silver finishes.)

7 Electrode materials

The choice of the electrode material depends on the welding products to be joined. If the welding metal has great thermal conductivity (e.g. copper), we need to use an electrode with low thermal conductivity to keep the heat generated in the area of the weld spot and not allowing it to be easily diverted away from it. This would be tungsten, tungsten alloy or molybdenum electrodes.
If, by contrast, we are welding materials with low thermal conductivity, copper, tungsten copper, or copper chrome zirconium electrodes are used.
They prevent overheating of the welding area.
By using different electrode materials at the upper and lower electrode, the weld spot can be moved deliberately away from the centre. However, this is only possible if no particular electrode material is required due to the welding materials.

8 Electrode geometry

By changing the electrode geometry more or less heat can be introduced into the part (analogous to the electrode material, chapter 7). This is also due to the corresponding contact resistances. In case of a small to dot-type contact, the respective resistance is greatly enhanced and at the same time the heat dissipation through the electrode is reduced; as a result the position of the weld spot is moved more toward the top or bottom in the welding material, depending whether the surface of the upper or the lower electrode is reduced.
However, the disadvantage of a small electrode is its reduced life. A small dot-shaped electrode integrates more quickly and therefore wears more rapidly. The objective should be the use of a preferably large electrode.

9 Weld heads

The spot weld head and the weld tongs are suitable for spot or projection welding as well as cleft or bridge welding, that is, the standard welding connections in resistance welding. The gap weld head and compacting tool are special methods of resistance welding.

9.1 Spot weld head

The spot weld head generally consists of an upper and a lower weld head. The lower weld head serves as anvil and lifts the part to be welded slightly from its seat. It must be ensured here that the contact between part and electrode is always guaranteed and the parts are never unsupported.
Another version of the lower electrode is its firm integration into the seat so that the part is always placed directly on the electrodes. A good contact between electrodes and the part must also be ensured here.
The upper tool is normally pneumatically powered; the exact welding pressure is controlled via a proportional valve and can vary between weld points depending on the parameters set. The follow-up behaviour is determined by the upper weld head (see chapter 5) and it is therefore important that the moved masses are preferably small for the weld heads to follow up very quickly over the respective depths. The weld heads from Credé Elektronik are therefore all equipped with springs, which – due to the spring hysteresis – can implement the applied welding pressure 1:1 without loosing time through controls and sensor detection.

9.2 Welding tongs

The product offering of Credé Elektronik distinguishes between two welding tongs: The pivot welding tong and the parallel closing welding tong.
The pivot welding tong is the simpler version of the welding tong. It is optimised for the follow-up behaviour and preferably small masses. It is relatively small for this reason and does not require much space. It is ideal for applications with small and difficult parts were a quick follow-up behaviour must be guaranteed. The welding tong has a floating design, which means that the tong can adapt to the parts if they are bent and the tong does not straighten or bend the parts as this would cause changes of the welding pressure and the welding result. The only drawback lies in the fact that the welding pressure is set via the mechanical preload of the spring and thus welding is always possible only with one pressure per tong in one run.
With the parallel closing welding tong, the welding force is set via a proportional valve and can therefore differ from welding point to welding point. As the name indicates, it closes in parallel and is thus able to enter small clearances, however, the rear part of the tong requires more space because of the guides. Both legs of the parallel closing welding tong are spring cushioned for fast follow-up behaviour. The tong always closes around a centre and slightly floats around this area because of the dual-sided spring mechanism (0.1-0,2 mm).

9.3 Gap weld head

The gap weld head is used wherever the welding area is not accessible for design reasons from the top or bottom but only from the top. A distinction is made between welding only on

one contact side and the separate contacting of both parts. The second approach represents the principle of spot welding; in the first scenario a weld pool develops between both electrodes, which has to develop far enough to transit from the upper to the lower part and liquid material is thus generated in both parts. A joint material bond is then created during solidification.
The problem with this welding method is that the substrate of the welding parts must be solid and heat-resistant. The measuring results of the welding depth are falsified if this is not guaranteed. The effect may go far enough so that the welding depth can no longer be used as quality criterion to assess the welding result.

9.4 Compacting tool

With compacting, bundles of individual strands are welded into a rectangular format.
To delimit the format toward the sides, ceramic elements are attached to the lower electrode or clamped in place with appropriate mechanics. The upper electrode enters the slot thus created and compacts the strands through resistance welding into a rectangular shape.
The challenge is presented by the high precision of the upper and lower electrode since a lateral burr otherwise arises from compacting. Tools equipped with opening ceramic elements can be easier loaded and removed.

10 Resistance welding, its geometry and dimensioning in the welding area

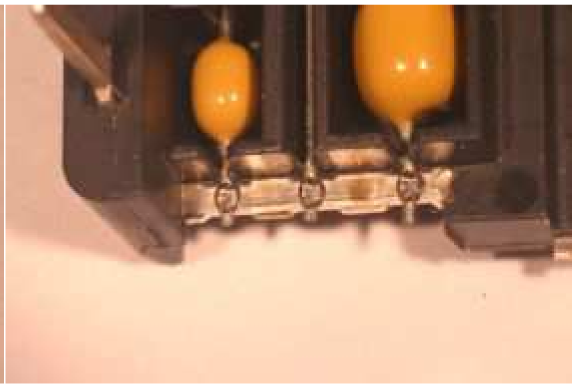
10.1 Spot welding

With spot welding, the energy for the welding process is generated by a small dot-shaped electrode specifically in a small area. The position for the development of the weld spot results from the combination of the material thicknesses and size as well as the materials of the electrodes.
Spot welding is primarily used for simple welding tasks, wherever relatively identical material pairs – both in material thickness and composition – are to be joined.
The geometry of the upper electrode is thereby relatively small and somewhat crowned. The smaller electrode means shorter tool lives of the electrode and thus longer machine downtimes due to electrode replacements. A crowned electrode changes its contact resistance in part by the electrode being broken in during the batch production process and therefore impacts the welding result.

10.2 Cross welding

Cross welding is used wherever parts do not contact each other with large surfaces but where one small part must be joined to another part and where certain positioning tolerances may occur at the same time due to automation. These tolerances lead to a change of the surface between the two parts and thus to a change of the contact resistance.

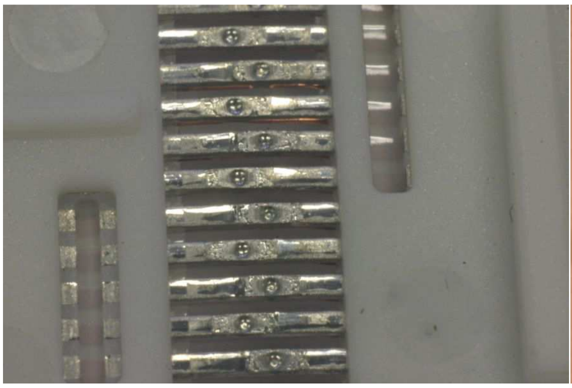
The tolerance through positioning therefore directly affects the quality of the weld. To be able to still achieve process capability in spite of the positioning tolerance, cross welding is used because the same resistance conditions keep occurring here.

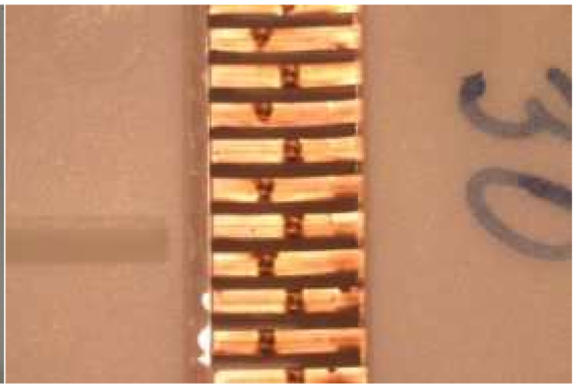



The electrodes can be designed very large and simple.
This reduces costs and increases the life of the electrode at the same time.

10.3 Projection welding with weld bolds

With projection welding, a weld bold is pressed into one of the welding parts. This weld bold causes a spot-type contact between the parts and therefore a high contact resistance.
When the appropriate current now flows through the parts, the weld spot is created exactly between the parts where it is desired. The welding process and the welding parameters are such that a very high but short weld pulse is principally given to take advantage of the high contact resistance as long as it is available.
If the control variable (current, voltage, output) increases too slowly, the weld bold is shaped back again before a weld spot can be created.
The requirements on the control behaviour of the control systems and the mechanics of the weld head increase considerably here. (See chapters 5 and 2.3).

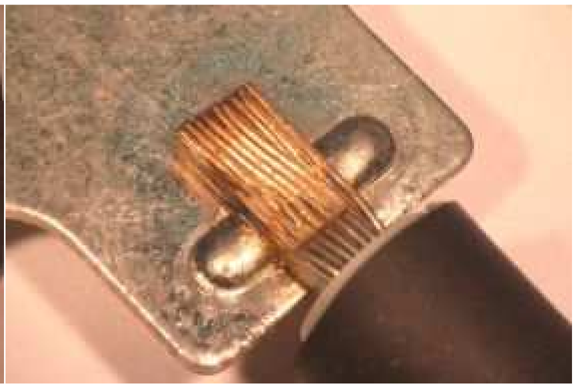




If possible, the weld bold should always be formed in the part with the greater material thickness. (Exceptions with different material pairs: The material with the greater thermal diffusivity). (Harder material is more difficult to weld than soft material.)
In the case of harder material, the welding connection breaks ‘glasshard’.
Another advantage of projection welding lies in the fact that the electrodes can be designed very large and unsophisticated. This reduces costs and increases the life of the electrode at the same time.

10.4 Projection welding with weld ridges

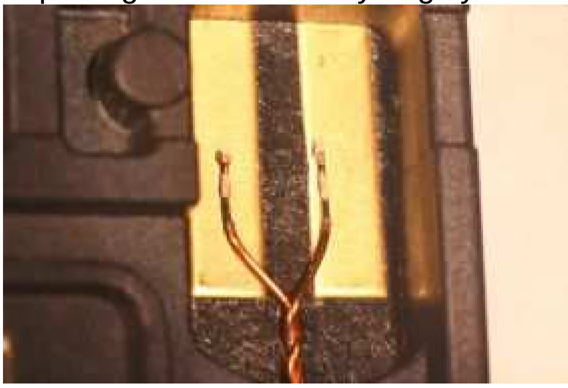
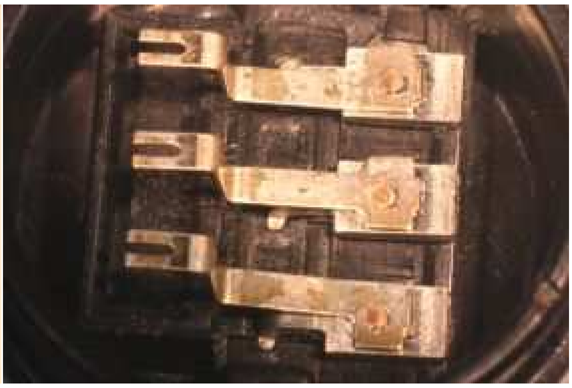
In projection welding with a weld ridge, the weld bold from chapter 10.3 is replaced by a lengthwise ridge. The reason are positioning tolerances in an automation process or very small long parts that cannot be welded with cross welding and would slide off to the side from a weld bold.

The advantages are the same as with projection welding using a weld bold.

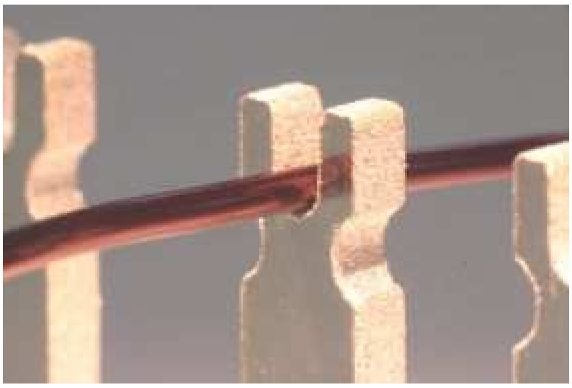
10.5 Gap welding

Gap welding is used wherever the parts to be welded do not allow any access for the electrode from underneath. Both electrodes are thereby lowered from the top onto the material to be welded and have a gap between the electrodes. The dimension of this gap is another relevant parameter with gap welding.
The size relationships of the parts to be welded should be arranged so that the thinner part always lies on top of the thicker part and the electrodes therefore begin with the welding process on the thinner part.
The weld spot in the pure gap welding process is created between the electrodes and must develop far enough (from the thin into the thick part) for both materials to become liquid.
There is a gap welding version that also uses weld bolds or where the second electrode contacts the part indirectly and spot or projection welding is performed again. With all versions the base material must preferably be temperature resistant to prevent interferences with the welding process, since the entire contact surface of the welded parts melts thus falsifying the measuring results. In most cases this cannot be ruled out at 100% and compromises must be made when determining the welding depth.
In the pure gap welding process without weld bold and small welding parts, the welding depth argument is already largely reduced.

10.6 Welding with weld yokes (hot staking)

Welding with a weld yoke is a mix of a crimped joint and a welded joint. Defined shunts of the electric circuit exist during the welding process aimed to cause the general heating and melting of the materials. The correct dimensioning of the yoke is therefore decisive. The quality criteria for process monitoring are no longer as pronounced as with true resistance welding.



The key advantage of the method lies in the fact that the electrodes are no longer in direct contact with the part in the yoke. Consequently, material with poor surfaces can be processed at this point without the burning of these materials leading directly to a deposit on the electrode. It becomes thereby possible to achieve relatively acceptable electrode service lives in spite of the poor basic conditions.
This even includes the scenario where enamelled wires are melted in advance during the heating phase of the yoke and are subsequently welded together with the yoke. This would not be possible with a conventional resistance welding method, since the enamelled wires would insulate completely.
Thus, the main area of application is the welding of wound wires, e.g. in motor production.
The electrodes generally have a bevel of 3-5° to affect a better closure of the yoke. Welding tongs are normally used.
The position of the wire in the yoke determines the quality of the welding result; it must be ensured through additional measures that the wire is always inserted and positioned as deeply as possible in the yoke.

10.7 Welding with weld bridges

Welding with the weld bridge has the same application field and background as Hot Staking, except the geometric implementation is designed differently. Depending on the design and the space situation, one or the other method is used in actual application.

The geometry of the electrodes can be designed each at 90°; the electrode also has a partial bevel at the top side of the bridge.
The position of the wire in the bridge also determines the quality of the welding result; it must be ensured here as well through additional measures that the wire is always placed and positioned preferably in the radius of the bridge.

10.8 Compacting

With compacting, bundles of individual strands are welded into a rectangular format.
This method is always used when the strands must subsequently be welded together with another part or to replace a cable lug. Cross-sections from 0.5 mm² to 25 mm² are possible; the degree of difficulty increases the thinner the individual strands.

11 Geometry of plastics around the welding area

More and more hybrid components (pressed screens with plastic surrounding them) are used where additional electronic components must be added or need to be joined.
The available package space and the accessibility of the welding area with the electrode become increasingly restricted.
The electrodes should not fall below the dimensions of 4 x 4 mm, since this would otherwise result in extremely short service lives. All plastic materials must be kept away within this area, including the area for opening stroke and automation tolerances.
As soon as the electrode begins to touch the plastic during welding, it begins to melt and slight residues remain on the electrode. This residue burns away during the next welding process. More and more material is thus deposited on the electrodes, increasingly affecting the contact resistance between electrode and part. This makes the process capability doubtful and small explosions may even occur due to contact problems.
To keep the tolerances in positioning the part as low as possible, fixing the part through position holes of the pressed screen is recommended since no tolerances through shrinking and mould removal bevels are generated here, as is the case with plastic.
The parts to be welded should have as few sealing areas as possible between the pressed screen and the plastic in the welding area or as far as possible away from the welding point.
The pressed screen is heated during welding up to the melting temperature of the material (with copper approx. 800 °C); this heat is dispersed through the pressed screen and liquefies the plastic at the sealing edges.
The plastic evaporates partially and causes a quicker fouling of the electrodes. However, if the plastic is quite close to the welding area, the liquid plastic behaves like solder and flows into the area of the greatest heat and thus into the welding zone; this can lead to the situation where any bonding of the materials is prevented. At any rate, the quality of the weld is markedly reduced and the process capability questionable by increased fouling of the electrode.

12 Impact on the welding process and the process capability

12.1 Contamination of the electrode

Previous process steps may cause the development of contamination on the welding material, which may not even be avoidable since the previous process could otherwise no longer be carried out.
Welding technology must therefore be clearly knowledgeable of other processes beyond the actual welding task, especially of their auxiliary material and by-products that may impact welding and the process capability.
The contamination of the electrode is primarily caused by carbon residues generated during the welding process through the evaporation of foreign substances. These residues are visible as a black coating on the electrode and alter the contact resistance from electrode to welding material. This contact resistance increases steadily the stronger the contaminations become. As the contact resistance increases, more and more energy is introduced into the parts and the welding process constantly increases. Because of the constantly rising energies in the welding process, the electrode experiences increasingly higher loads, since it also becomes hotter and hotter. This creates a spiral where the individual effects raise to a higher power.
It must therefore be ensured for a preferably constant process and consistent quality that all foreign matter, able to cause contamination on the electrode, is removed.
Contamination through adhesives, paints, silicone or glass coating even act as insulation and inhibit the entire welding process.
To show contaminations on the surface, touch-up sticks are used that classify the surface tension on the parts. These sticks are borrowed from bonding technology where a 100% clean surface is required for the process. (Arcotest)

12.1.1 Oils/greases from punching processes

Oils and greases are primarily used with punching processes; however, they are sometimes also used for lubrication with other process steps. These lubricants remain on the surface after the liquid part of the lubricating emulsion has evaporated. Also with the volatile oils, only the liquid part of the emulsion evaporates; this is only accelerated by adding alcohol.
The lubricant residue remains.
Carbon residues then develop during the welding process and the spiral referred to in chapter 12.1 begins to spin.
We need good basic conditions for process-capable welding and this is only given with clean parts. Either the lubricant has to be dispensed with or the parts need to be cleaned (galvanic) after the process that used lubrication.
The next alternative is that we do not use any lubricant but a cleaning agent, called, isopropyl alcohol, which also has slightly lubricating properties. If all this cannot be implemented, the electrode must be regularly cleaned during production; this is done with brushes or diamond grinding slips.

12.1.2 Passivation / Theolenes

Passivation is an oxidation protection preventing oxygen from coming into contact with the surface of the materials. Passivation is used, for example, with gold, silver or copper surfaces aimed to prevent them from turning black. This has optical reasons, on the one hand, but the developing oxides also cause problems with the contacts, on the other hand (gold-plated plug contacts). It can therefore be assumed that wherever these surfaces are used and plug contacts exist, that passivation was used for their protection. Passivation, in this case, consists of a sulphuric bond where the sulphur molecules always align themselves so that oxygen cannot come into direct contact with the material surface, able to react there.
These sulphur molecules incinerate in the welding process and precipitate as cinder on the electrode. This changes the contact resistance as outlined in 12.1.
The amount of the passivation applied plays a crucial role for the process capability of the weld. If the application was extremely low, a welding process with integrated cleaning cycle can be implemented.
With a passivation with Oxiban 60, the welding process can still be realised fairly well and is process-capable.

12.1.3 Plastics in the welding area

Analogous to chapter 11, “Geometry of plastics in the welding area”, treated in a separate chapter because of its relevance, we would once more like to draw attention to it.
When plastics become liquid, they behave like solder always flowing to the warmest area, which is the welding zone. In the extreme, these plastics can prevent a proper structural bond of the materials and the parts adhere together instead of welding them together. The liquid plastics are generated through the heat conduction of the basic materials during the welding process.
The plastic is simply melted at the sealing edges between the pressed screen and the plastic body.
These sealing edges directly on the pressed screen must be removed as far as possible from the welding area. In this manner, the heat radiation via the pressed screen into the plastic is reduced.
However, the sealing areas must be absolutely included as quality criterion in goods receipt inspection, because increasingly strong injection skins develop and the plastic is able to move further and further into the welding area.
The next problem occurs when the electrode comes in direct contact with the plastic. The plastic is melted by the hot electrodes after welding and remains on the electrode. More and more plastic gradually builds up until it enters the welding area, causing faulty welding processes. This is generally detected, but leads to increased reject rates and in the extreme case, it can also jeopardize the process reliability. It is important here to observe all tolerances of the automation process.

12.2 Punching burr

If the punched part has a poor engineering design, the burr can end up directly on the electrode thus reducing the contact surface to the electrode.
Localised overheating then always occurs in this area of the electrode and the electrode will sustain a notch in this area. This affects the batch production process, since the contact resistance between the electrode and the part is changed, depending on the burr and features of the notch. We no longer have consistent prerequisites for the batch process.

12.3 Position changes / Tolerances

Position changes and tolerances always affect the weld and the process reliability when they impact the resistance ratio. Weld ridges or cross welding are therefore used with the aim to reduce these positioning influences, since in these cases the positioning tolerance no longer affects the resistance ratios.

12.4 Material hardness

The material hardness has a marked impact on the quality of the weld. It must therefore be insured for batch production that the material hardness of the materials does not vary too much.
In principal, hard material is more difficult to weld than soft material. With a hard material, the grain boundaries are already so much condensed that they will not engage into a bond with the other welding partner.
If a significantly harder material is suddenly used in batch production, the welded joint becomes much more brittle and during an adhesion test, it breaks away as hard as glass. A welded joint where the structures have bonded together exhibit a "tough" breaking behaviour with much higher pull-off forces. Ideally, the bond leads to a plugging out of the materials.

12.5 Oxidations / Storage times

Storage periods of the parts cause oxidation layers and intermetallic bonds preventing a welded joint with the same parameters.
For this reason, copper surfaces are coated with an anti-oxidant or an additional surface, since the oxide layers develop very quickly here, depending on the humidity and access to air.
The intermetallic bond also increases with tin-plated parts during storage. As soon as it is fully developed, the parts can no longer be welded or soldered.
Clear storage times must therefore also be defined and observed here to ensure process-capable batch production.
With blank copper parts, e.g. the storage time is 7-14 days and 6 months for tin-plated copper parts.

13 Process validation and its scope up to DOE

The objective of process validation is that a process delivers a product in a reproducible manner, corresponding to the predefined properties and quality requirements.

Process validation therefore not only includes the welding process but the entire system with all automation concepts and possible defects developing due to automation tolerances, affecting the welding process. Add to this differences in the parts to be welded with the impacts from chapter 12.

In process validation, thresholds of the relevant welding parameters are narrowed down and a tolerance for well welded products is defined.
First of all, the required quality must be defined.
In the next step, the welding parameters applied to maintain this quality are determined.
The tolerance limits are strongly reduced for this purpose. Each suspected reject part is examined and if it turns out to be an OK part, the respective threshold is expanded. As soon as a threshold proves to be correct and identifies a NOK part, this threshold must be ‘frozen’.

Process studies are completed at this point at most companies; certain influencing variables have contributed to process validation within this test period – at least the ones constantly occurring in the facilities. For example, the tolerances of automation technology.
A DOE (Design of Experiments) goes one step further here and attempts to deliberately generate and detect interference factors. But even here, only already known interference factors can be mapped and simulated, see chapter 12.

The time expenditure for such as study increases drastically. Simply procuring the samples can become a problem. Process validation / DOE can therefore only be conducted by the customer himself after the first parameters have been determined.
The advantage is that the user must intensively preoccupy himself with the entire matter during this task to enable him to detect and correct new problems, previously not recorded, more quickly.

The study on the process capability is thus, realistically seen, never fully completed during the entire lifecycle of the product since new factors can be introduced into the process all the time. Even the wear of seats and retainers can cause quality problems.

14 In-process QA

To be able to make a statement on the quality of your welds, a destructive test is still the best evidence and unavoidable for proof of quality. There are influencing variables which are not detected by the quality thresholds of the welding parameters, but which will absolutely lead to a poor welding result (e.g. sudden change of the surface finish with an additional nickel layer). Such defects can only be detected by in-process destructive quality tests.

Micrographs of welds are very difficult to interpret and are quite costly. Furthermore, the exact position of the micrograph in the area of the weld spot must be ensured.
The setup of the test bench should correspond, as much as possible, to the forces actually encountered in the field; possibly occurring tolerances in the test bench should be designed just as in the actual application to obtain realistic and useful values.
When generating samples, it is important that the welding connection is not subjected to a load before the actual test. The test can otherwise not be used to make a valid statement.

14.1 Tensile / Compression test

The welding material is pushed or pulled apart via a plunger through appropriate gripping systems.
This test meets 90% of all tasks and should not be missing from any batch production.
The essential difference of the test devices lies in the fact whether the tension or pressure is applied constantly via a motor or generated via a crank wheel by the personnel, thus exhibiting variations.

14.2 Torsion test

The torsion test checks the welded material at the joint through a torsion movement. The resulting moment is recorded.
This test device is also available motor-driven or manually. However, its application range is much lower than the tensile/compression test, since the welding material must be readily accessible for the tools in order to obtain useful values.

14.3 Peel test

The peel test is an absolutely subjective assessment of the welded joint. The welded material is separated here by a vertical rotational movement. With a good joint, corresponding material should always be plugged out and thus remain attached on one of the elements.
The peel test delivers a statement of the quality of a welded joint relatively quickly and is primarily used in the phase of parameter determination to save time for elaborate tensile tests.

14.4 Micrographs

Micrographs are used to demonstrate in the structure that the materials have bonded and the grain boundaries flow into each other.
Even experts do not always agree on the interpretation of micrographs; professional opinions should therefore be consulted as backup in case of not clearly positive results.
Welding with refined surfaces is always assessed critically since certain residues of the original surfaces are still visible, exhibiting a separating layer und the base material has therefore not yet bonded together.
However, these are intermetallic bonds, which will pass a tensile test and lead to plugged out materials in case of OK welds. The drawback of an intermetallic bond is that it is very hard and brittle, exhibiting poorer properties in vibration tests.
This welding type is completely sufficient for the tensile test and the bonding of the materials. Only the vibration resistance requires the implementation of additional mechanical solutions, stabilising the part and preventing it from swinging up.

15 In-production visualization and lot documentation

All control systems from Credé Elektronik provide the option of transferring all process-relevant data via an interface into a parent PC. Large companies can use this interface to prepare the data for internal archiving. For small and medium-size companies we offer additional software that can be used to perform the visualisation and lot documentation on a provided PC.
This gives you the option to view long-term evaluations.
Additional assessments with the Gauss distribution curve on the set thresholds as well as the Cpk or Cmk values can be carried out.
The entire welding parameter set and the project structure programmed on your system becomes visible with the individual parameters and can be stored.

16 Bibliography and sources

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