Gloria Wetzel, Tobias Broda, Steffen Keitel

Optical measurement of spot resistance welding guns

Abstract: Spot resistance welding processes may be troubled by deviations of electrode positions (contact fault). The article presents this issue in relation to robotic spot welding guns used in high-volume production and manual spot welding guns used in repair works. The article presents the method for optical measurements of the above named welding guns, enabling the determination of an electrode contact fault, as well as compares both types of welding guns in this respect.

Keywords: spot resistance welding, spot welding guns, electrode contact fault

DOI: *10.17729/ebis.2016.1/3*

Introduction

Resistance spot welding is the most widely used welding method in the automotive manufacturing industry, especially car body construction, and is frequently used not only in manufacturing but also in repair work. However, conditions vary widely between welding guns found in the manufacturing hall and repair shop.

Resistance spot welding in automobile plants is usually carried out by robot-controlled welding guns using X- or C-guns (see Figure 1).

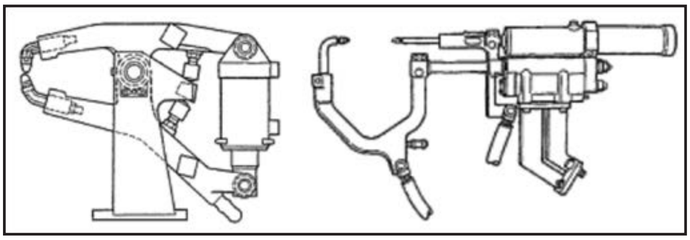


Fig. 1. Diagram of an X-gun (left) and C-gun (right) [1]

Standards have been drawn up and implemented in design, throat depth and drive to address the diversity. X- and C-guns used in mass production usually have a very high level of stiffness.

Welding machines in repair welding are largely similar to robot welding guns, albeit significantly smaller and lighter as they are always manually operated – a restriction in this type of equipment. Gun weight is an important feature, as it cannot exceed 16 kg [2]. The highly limited throat depth has a favourable effect on weight requirement and accessibility for repair welds since the welding work involves the entire vehicle rather than just the vehicle frame, as is the case in manufacturing. C-guns have prevailed in repair work as they ensure a predefined electrode force regardless of throat depth.

The automotive industry also requires savings in production costs and resources aimed towards reducing weight and power consumption while maintaining or improving passenger cage safety [3]. This especially involves high-strength and ultra-high-strength steel, placing additional demands on the technology used. Materials with higher strength require higher electrode forces, and this affects welding gun stiffness. Car manufacturers also require repair shop equipment that produces the same

Dipl.-Math. Gloria Wetzel, Dipl.-Ing. (FH) Tobias Broda, Prof. Dr.-Ing. Steffen Keitel – SLV Halle GmbH

weld strength as you would find in series production. Transformer guns have become state of the art as energy turnover is highly favourable, providing sufficient welding current for high-strength and ultra-high-strength working materials [4].

Many studies have shown that a welding machine's mechanical properties must be regarded at least as equivalent to welding parameters in process safety [5]. According to [6] and [7], contact failure between electrodes with deflection and eccentricity parameters as well as contacting and repositioning of the electrodes are highly influential on the areas of application for the process as well as welding quality and the electrode life.

Aim and scope of the study

An ongoing joint project of SLV Halle GmbH and Anhalt University of Applied Sciences (BMWi, IGF project No. 18159 BR) aims to examine the influence of repair conditions on the mechanical properties of resistance spot welding. In addition to determining welding gun handling and operating limits, this project partly focuses on the influence of welding machine properties on welded joins.

In particular, we will examine the contact features in robot-controlled C-guns and repair welding guns at varying throat depths by optical measurement at various electrode forces on the welding gun. The deflection and eccentricity measured should indicate welding gun stiffness and weld quality while highlighting the differ-ences between welding guns as used in manufacturing halls and repair shops.

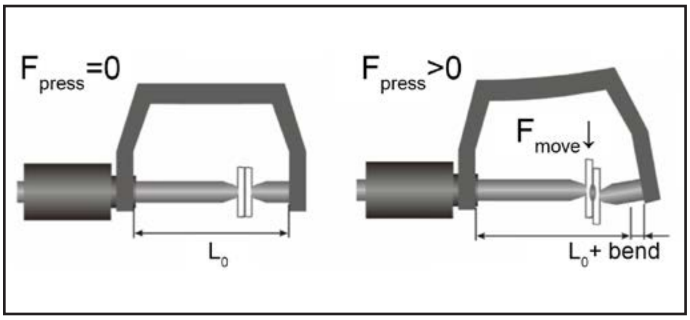


Fig. 2. C-gun deflection with electrode malpositioning [4]

Contact failure in spot welding equipment

Arm deflection causes malpositioning in mobile electrode arms while applying electrode force in the first and second pulse in spot welding (see Figure 2). This causes contact failure by deflection and eccentricity as described below.

Explanation of terms

In spot welding, *deflection* refers to the gun axes deviat-ing from their intended alignment due to electrode force according to [8] (see Figure 3).

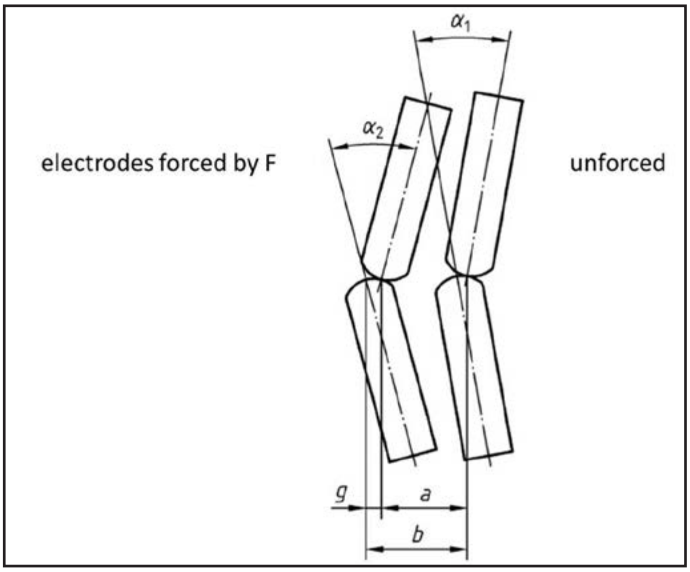


Fig. 3. Contact failure in spot welding equipment [8]

This results in deflection α:

$$\alpha=\alpha_2-\alpha_1 \quad (1)$$

Eccentricity in spot welding equipment refers to the distance between electrode working face centres displaced by mechanical electrode force on the working material surface (see Figure 3), and is calculated as follows:

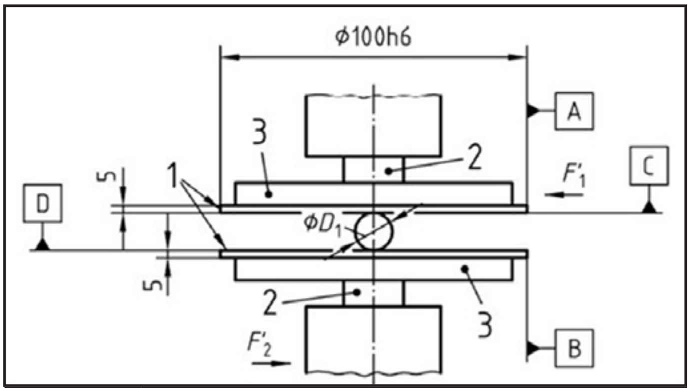
$$g=b-a \quad (2)$$

The values required for deflection and eccentricity can be determined in the actual situation.

Determining contact failure according to [8]

[8] describes contact failure measurement in a welding machine (see Figure 4) using two toughened discs instead of spot-welding electrodes in such a way as to keep the opposing

surfaces parallel and eccentricity less than 0.05 mm. We placed and centred a steel ball between the two discs. The diameter of the ball and the material in the toughened discs were selected such that no impressions would be formed on the contact surfaces at full force.



1	toughened discs
2	punch
3	clamp
A, B, C, D, F_1, F_2	faces and forces for positioning and determining contact failure of electrodes deviating from their intended alignment

Fig. 4. Measuring equipment for contact failure in spot welding equipment

In addition, [8] specifies the measuring equipment including calibration and accuracy to be used in measuring deflection and eccentricity parameters (such as verniers).

Optical contact failure measurement

We measured contact failure using optical measuring equipment to avoid inaccuracies caused by operator error from using manual measuring devices. This measurement method also offers the advantage that it measures movement in two and three dimensions more easily.

Optical measuring equipment and experimental setup

We used a three-dimensional optical measurement system for the investigations at SLV Halle GmbH. A stripe pattern is projected onto the object by a projector during measurement, which is deflected at component edges, curves, holes and so on. Two cameras record this pattern for conversion into three-dimensional coordinates by software triangulation. Several measurements are needed to measure an object. Overlaying the resulting data for the entire object usually involves reference points glued to the object, and the software uses these reference points to line up the individual measurements. Reflective components complicate optical measurement, which is why highly reflective metals are often matted using a spray before measurement.

There was used a specifically customised measuring device from [8] to measure the welding guns in this project. First, we attempted to take measurements from a metal cylinder instead of a ball to detect welding arm deflection (see Figure 5).

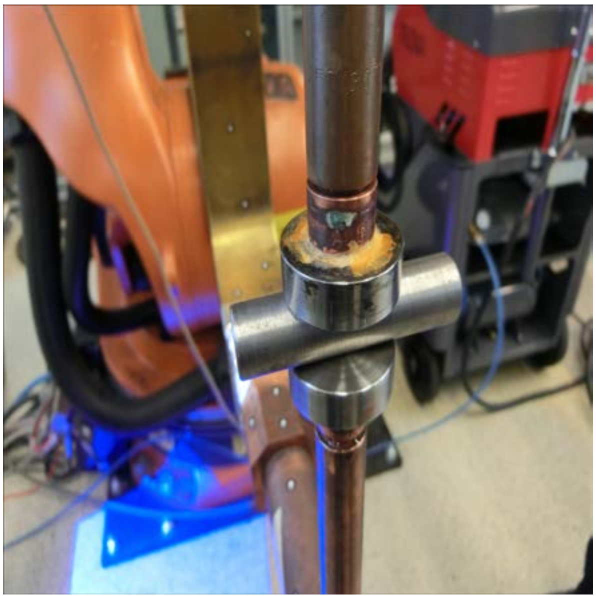


Fig. 5. Device for measuring contact failure on a cylinder

This proved especially difficult when positioning the cylinder against the welding gun's throat depth. We performed subsequent tests on a metal ball due to the expected risk of error in measuring deflection due to misalignment as well as the limit of deflection to the axial direction of the cylinder. We positioned the ball between the electrode faces by using two matched shells machined such that one shell was applied to the lower electrode first, the ball placed inside it, and the second shell placed on the other side. We removed the shells after applying electrode force (see Figure 6).

Fig. 6. Device for positioning the ball for measuring contact failure

Repair welding gun measurement

We used welding guns from various manufacturers to investigate the influence of conditions on the repair welds. As an example, we performed an optical meas-urement on a welding gun at two throat depths, 85 mm and 510 mm. Repair welding guns especially tend to-wards measurement inaccuracies as most of these welding guns are manually operated and have no other means of fastening that would be suitable for determining mechanical equipment characteristics. SLV Halle GmbH designed a fitment (see Figure 7) for clamping the welding gun in such a way that it could be compared against a robot welding gun.

Fig. 7. Repair welding gun including bracket and optical measuring equipment

The repair welding gun was clamped using the fitment we developed. We matted part of the electrode arm to avoid excess reflection, and attached the reference points. After that, we measured the welding guns using the lowest possible electrode force F_E as well as an electrode force of approximately 4 kN. Figure 8 shows the superposition of the repair welding gun at short throat depth (blue at F_E ~ 0 kN and grey at F_E ~ 4 kN).

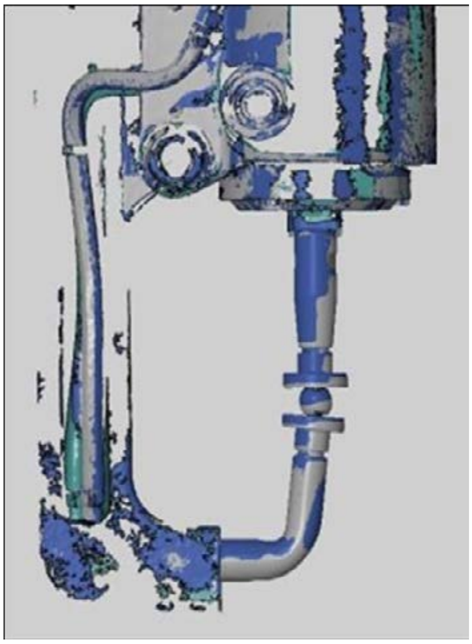


Fig. 8. Representation of the optically measured repair welding gun at short throat depth (blue without force, grey with force on the electrode)

Figure 9 shows the welding gun at long throat depth superimposed at different levels of electrode force.

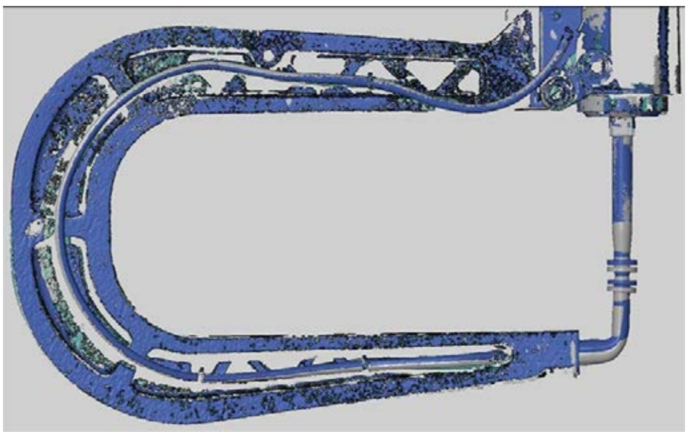


Fig. 9. Representation of the optically measured repair welding gun at long throat depth (blue without force, grey with force on the electrode)

As described above, the welding gun measurement requires several individual measurements. Accurate measurement of whole electrode arms is not relevant in calculating contact failure, so we focused on representing electrode shafts and the device for measuring contact failure.

Robot welding gun measurement

As with the repair welding gun, we fitted the robot welding gun with adapted electrode caps and positioned the ball. The robot welding gun (see Figure 10) we used had a throat depth of around 310 mm.

Again, we matted part of the object measured and the electrode arm and attached reference points. Optical measurements were taken at around 0 kN and 4 kN. Figure 11 shows the superposition of these two conditions.

Comparing results from optical measurement in the repair welding gun and robot welding gun as used in series production

The *deflection* in the welding gun was not calculated using the formula in [8] as there is an easier way for assessing the optical measurement by software. Fitting cylinders can be placed around

Table 1. Angle between the electrode axes on the welding guns measured

Welding gun	Angle between electrode axes in degrees at	
	F_E ~ 0 kN	F_E ~ 4 kN
Repair welding gun at short throat depth	5.00	5.96
Repair welding gun at long throat depth	1.27	2.72
Robot welding gun	0.84	0.87

the electrode shafts with axes corresponding to the electrode axes. This yields the angle between the electrode axis on application without (F_E ~ 0 kN) and with force on the electrode (F_E ~ 4 kN) (see Table 1). The repair welding guns showed deflections of 0.96°, 1.45° and the robot welding gun showed a 0.03° deflection.

To determine *eccentricity* described before, we took cross-sections of the object measured in the direction of the electrode arm, determined the centres of the respective electrode surfaces, and used the resulting coordinates to determine the eccentricity in electrode arm direction.

Figure 12 shows an example of the robot gun in cross-section and the coordinates of the electrode surface centres. The gun at F_E ~ 0 kN is shown in red, and black for F_E ~ 4 kN.

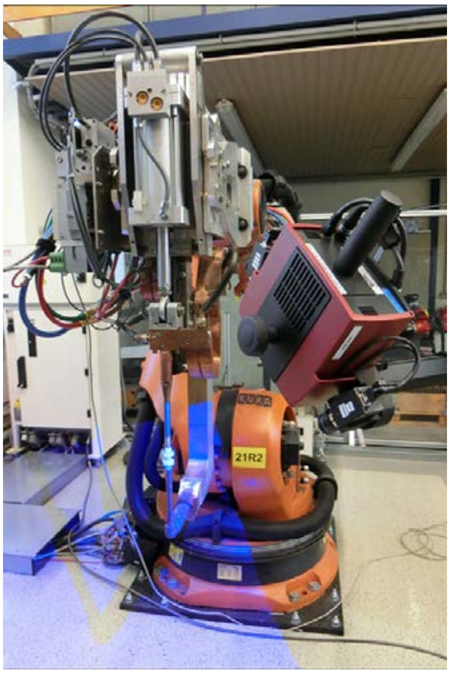


Fig. 10. Robot-controlled C-gun with adapted electrode caps and ball

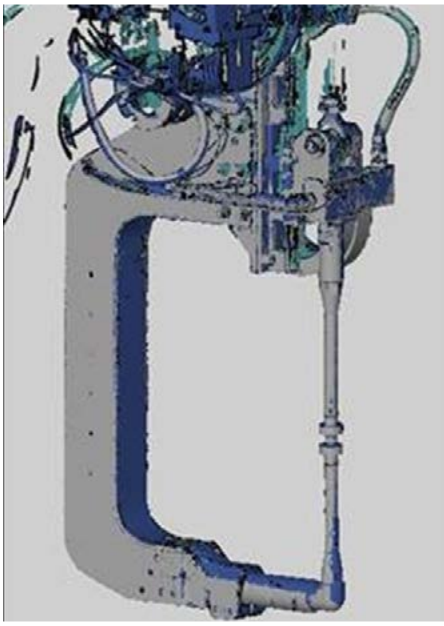


Fig. 11. Representation of the optically measured robot welding gun at long throat depth (blue without force, grey with force on the elec-trode)

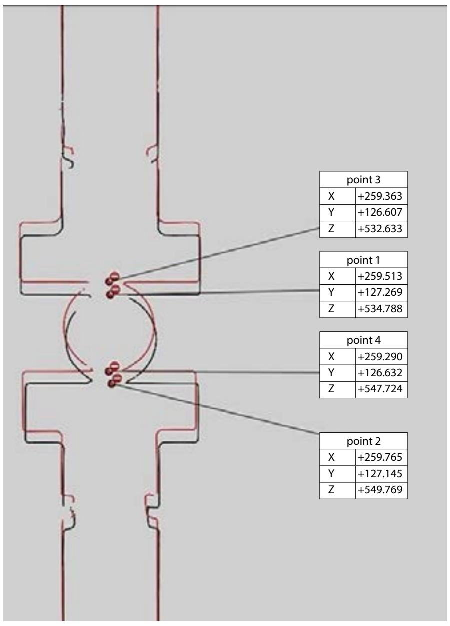


Fig. 12. Cross-section of the electrode arm of the robot welding gun in the unloaded (red) and loaded (black) state

To calculate the eccentricity g according to [8], we used points 3 and 1, shown here, to determine a and points 2 and 3 for determining b.

The robot welding gun showed an eccentricity of 0.252 mm compared to the repair welding gun's eccentricity of 0.177 mm at short throat depth and 0.168 mm at long throat depth.

We additionally determined *stiffness* of the welding gun to reach a conclusion on its behaviour. This was calculated in a similar way to spring stiffness (spring force over deflection distance) by electrode force over deflection distance. We also determined the latter using the coordinates from optical measurement. The robot welding gun and repair welding gun at short throat depth showed the same stiffness (2 kN/mm) at an electrode force of 4 kN, while the stiffness of the repair welding gun at long throat depth was relatively low (0.5 kN/mm).

The results from the repair welding gun at short throat depth and the robot welding gun show that slight deflec-tion correlates to a high level of stiffness. Even so, we did find major differences in eccentricity that were due to the length of the lower electrode shaft. Longer lower electrode shafts may result in larger displacement in electrode surfaces towards one another despite lighter deflection. The repair welding gun with long throat depth was not as stiff and deflected relatively heavily, but still showed only slight electrode surface displacement.

Welding tests

We performed a number of welding tests to assess the effect of conditions on the mechanical and technological properties of resistance spot welds as applicable in repair conditions. We included welding area charts with different gun arms and constant electrode geometries (B-16-6-cap) taking the same type of weld on 22MnB5+AS material at 1.0 mm gauge and 1.5 mm gauge as an example (see Figure 13).

Test conditions in welded joints showed that the current ranges were similar at the same electrode force (F_E = 4 kN) and welding time (Short:Medium:Long ≙ 170ms:680ms:340 ms). The results from welded joints using the robot welding gun and repair welding guns were similar despite different mechanical properties of the welding guns. Figure 14 shows the welding areas.

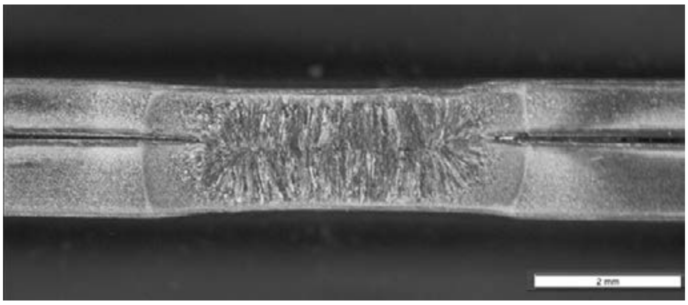


Fig. 13. Macrosection of a weld on 1.0 mm gauge 22MnB5+AS140 and 1.5 mm gauge 22MnB5+AS100

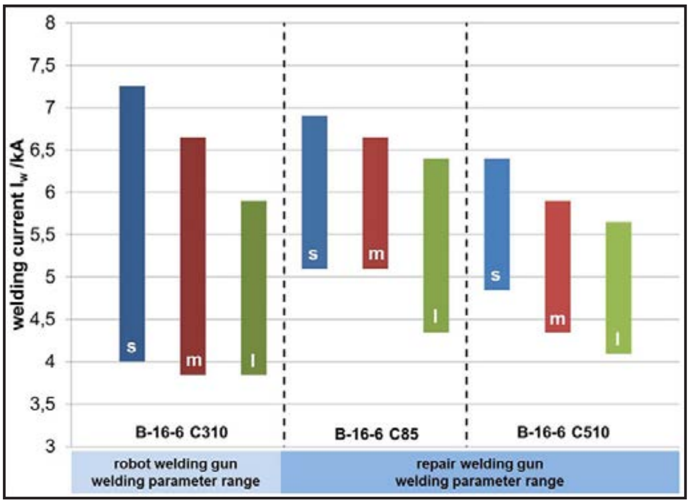


Fig. 14. Welding current ranges on the electrode arms examined

Conclusion

We have generally described the contact failure and procedure for determining mechanical parameters in [8] for spot, projection and seam welding equipment. This is the first comparison between repair and robot welding guns in estimating the characteristics of repair welding guns, and demonstrates how contact failure may be determined by optical measurement. The measurements showed that short throat depth in a repair welding gun performs in a similar way to a robot welding gun, while stiffness decreases in longer arm geometries. Welding gun eccentricity is similar, so longer arm geometries show virtually no electrode displacement.

Our welding tests have shown that differences in welding arms do not give rise to restrictions on the final weld.

This study was limited to C-guns. We will be studying X-guns in future contributions.

The method of measurement presented in this study is aimed at identifying failure patterns and testing welding parameters in industrial applications.

Acknowledgements

The IGF project 18159 BR by the DVS research association was sponsored by the AiF as part of a programme towards promoting joint industrial research (IGF) by Germany's Federal Ministry for Economic Affairs and Energy pursuant to a decision of the German Bundestag.

References

[1] Zhang H., Senkara J.: *Resistance Welding*. CRC Press, Boca Raton, 2012

[2] DVS 2521-2: *Widerstandsschweißmaschinen für die Karosseriereparatur – Inverter-Leistungsteile, Transformatoren und Steuerungen – Klassifizierung*, 2011

[3] *Ultra light steel auto body final report*. American Iron and Steel Institute, Washington D.C. USA 1998

[4] DVS 2521-1: *Widerstandsschweißmaschinen für die Karosseriereparatur – Inverter-Leistungsteile, Transformatoren und Steuerungen – Beschreibung*. 2011

[5] Römer M., Preß H., Krause H.-J.: *Mechanische Eigenschaften von Widerstandspunktschweißeinrichtungen und ihre mathematische Erfassung*. Schweißen und Schneiden 41 (1989), vol. 1, pp. 17–22

[6] DVS 2907: *Empfehlungen für die Auswahl und das Vergleichen von Widerstandspunkt-, Buckel- und Nahtschweißeinrichtungen sowie Widerstandspunkt- und Nahtschweißgeräten*. 1991

[7] Römer, M., Preß, H., Krause, H.-J.: *Versuch-sergebnisse und Folgerungen zum Auf- und Nachsetzverhalten von Punktschweißmaschinen*. DVS 124, pp. 101–108

[8] DIN EN ISO 669: *Resistance welding – Resistance welding equipment – Mechanical and electrical requirements*. 2001