Capacitor Discharge Welding

Technical Data

Created at: 18.May.2001
Table of content

1. GENERAL INTRODUCTION .............................................................................................................................. 3
2. PREPARATION OF PIECES ............................................................................................................................... 4
3. MANUFACTURING PRECISION .......................................................................................................................... 6
4. POSITIONING OF PIECES .................................................................................................................................. 6
5. PROCESS PARAMETERS ................................................................................................................................... 6
6. MONITORING ....................................................................................................................................................... 7
7. INFLUENCE OF HEAT INPUT ON PRECISION (DISTORTION) ................................................................ 9
8. TENSILE STRENGTH ........................................................................................................................................ 10
9. TORSION RESISTANCE .................................................................................................................................... 11
10. WELDING QUALITY FOR ANNULAR PROJECTIONS ........................................................................... 13
1. General Introduction

Capacitor discharge welding, hereafter referred to as CD welding, belongs to the group of resistance welding. It is mostly applied for projection welding, with annular projection diameters of up to 120 mm being welded. What is particular about this process is that the energy required for welding is not taken from external electricity supply but from a capacitor battery, which is charged between welds. The actual welding time amounts to only about 10 milliseconds. Because of this short welding time, the energy is concentrated on the welding zone only. As the parts cool out rapidly, granulation is relatively fine as the short cooling phase leaves little time for grain growth. Steels containing carbon as well as carbonised parts can be welded by means of reheat impulses. Reheat impulses considerably reduce the hardness increase of the heat affected zone (starter effect). The symmetrical state of stresses caused by the parallel welding of the entire cross-section avoids fracture in spite of high hardness.

CD welding is characterised by two parameters, namely welding energy and electrode force. The welding parameters are adapted to the welding piece and adjusted correspondingly. The welding process will only be initiated if both welding parameters are within the acceptable tolerances. A part control, which monitors the part height, can be carried out prior to welding.

During the weld, the energy impulse creates a setting way by which the welding parts melt. If both welding parameters and part geometry are constant, both energy impulse and setting way will be constant as well. This results in a constant welding quality, which can be monitored.

Timing of current and setting way

![Graph of current and melting path](image)

Owing to the constant welding parameters, as described above, and the low heat impact, CD welding is particularly suited for welding of precision parts, e.g. gear parts.
2. Preparation of Pieces

The pieces are to be prepared in such a way that one piece has a projection and both pieces provide sufficient contact for the welding electrodes. The ratio between the contact area and the welding area should be >3:1 in order to ensure high electrode exposure time.

The welding pieces are mostly prepared for welding by mechanical processing. An annular projection is to be applied to one of the pieces, with a form varying according to application. Different forms of annular projections are displayed in the following.

The setting way is between 0.4 and 0.7 mm. The projection heights are to be adjusted to these values, with the heights being approx. 0.2 mm more than the setting way. This prevents the pieces from touching block during the weld, which would block the welding force for the projection. Due to lack of contact pressure, the melted material might be overheated and thrown out.

For welding with low fracture risk, the projection shapes should be undercut to form a “trench” for the melted material.

If steels containing carbon are welded, one or more reheat impulses are used to reduce hardness. The welded pieces remain under pressure after welding. The capacitors are re-charged up to a defined energy level, and another impulse is released. This energy heats up the welding zone and creates a starter effect.

The welding projection should be in the welding part with the higher carbon content.

An annular projection with advanced rim offers the advantage that the pieces centre themselves and thus render positioning in the welding tool unnecessary. The advanced rim should be contained in the softer material.
Annular Projection Geometries

Tolerances for lengths and angles according to DIN 7168
3. Manufacturing Precision

The tolerances for the projection measures correspond to DIN standards. The manufacturing precision that is reached on lathes is sufficient for the production of projections. The evenness of the projection top is to be below 0.05 mm in order to ensure that the annular projection has overall contact to the counter piece. If the welded part is to have a defined height, it has to be measured in relation to the projection top. The projection geometry might have to be created with limited tolerances. A constant projection shape and constant welding parameters result in correspondingly constant setting ways with a dispersion of < 0.05 mm.

4. Positioning of Pieces

The dimensions in the drawings are to be applied for positioning of pieces.

5. Process Parameters

The CD welding is characterised by the two parameters welding energy and electrode force. These parameters have to be adapted to the welding piece and are in proportion to the annular projection diameter or the welding volume.

**Standard values for machine layout:**

The welding energy E is proportional to the electrode force F.

E (kJoules) ~ 0.5 x F (kN)

The annular projection diameter D is proportional to the welding parameters.

D (mm) ~ 2 x E (kJoules) ~ F (kN)

**Examples:**

- Annular projection diameter = 20mm  Energy = 10 kJoules  Force = 20 kN
- Annular projection diameter = 70mm  Energy = 35 kJoules  Force = 70 kN

Variations of the welding parameters can be caused by material, material thickness and the structure of the secondary electricity circuit.
6. Monitoring

The weld is only initiated when all welding parameters are within the acceptable tolerances. The welding can be preceded by a part control. During the weld, the energy impulse creates a setting way by which the welding parts melt. If both welding parameters and part geometry are constant, both energy impulse and setting way will be constant as well. If a quality control was carried out beforehand, continuous monitoring of quality is easily possible.

All data relevant for welding quality are captured, evaluated, recorded and documented according to the requirements of ISO 9000 ff.

All values to be monitored are fixed in a test plan, together with the corresponding tolerances. Testing instructions are generated from the test plan for each charge. Within one test run, data can be recorded in shifts.

The basic illustration form is a bar chart, which shows all features to be examined. Values recorded within the fixed tolerances will be shown in green bars; outside the tolerances the bars will be red.

![Bar chart illustration](image)

If either the part control or monitoring of welding parameters shows that a part is faulty, the machine can be signalled to sort these parts out, to issue alarm signals or to completely stop operation.

A menu bar facilitates the choice of a different form of presentation at any time. The recorded data can be displayed as histograms, control index, individual values, etc.

Operation of the machines does not depend on the form of presentation.
Strom - Kraft - Weg - Diagramm

\[\begin{align*}
I &= 166.8 \text{ kA} \\
T &= 6.3 \text{ ms} \\
kT &= 12 \text{ ms} \\
l &= 199.2 \text{ Rs} \\
f &= 16.5 \text{ kN} \\
G &= 99.79 \text{ mm}
\end{align*}\]

Histogramm

\[\begin{align*}
166.2500 &\quad \text{DIG} \\
165.6250 &\quad \text{DIG} \\
165.0000 &\quad 178 \\
164.3750 &\quad 265 \\
163.7500 &\quad 27 \\
163.1250 &\quad \text{UT} \\
162.5000 &\quad \text{UT} \\
161.8750 &\quad \text{T} \\
161.2500 &\quad \text{T} \\
160.6250 &\quad \text{T} \\
159.9999 &\quad \text{T} \\
159.3750 &\quad \text{UT} \\
158.7500 &\quad \text{UT} \\
158.1250 &\quad \text{UT} \\
157.5000 &\quad \text{UT} \\
156.8750 &\quad \text{UT} \\
156.2500 &\quad \text{UT} \\
155.6250 &\quad \text{UT} \\
155.0000 &\quad \text{UT} \\
154.3750 &\quad \text{UT} \\
153.7500 &\quad \text{UT}
\end{align*}\]
7. Influence of Heat Input on Precision (Distortion)

Due to the short welding time, the energy concentrates upon the welding zone only. The highest temperature is generated on the projection top during the energy increase period. As the energy flow continues, the melting takes places mostly in the projection. Once the energy is reduced to approximately half the maximum, the actual welding process is finished. The continuously decreasing energy flow causes additional heat input.

In the area of the melted projection, the heat penetration depth amounts to <1 mm and with an even counter piece < 0.3 mm. The piece is additionally heated by the effect of material resistance, which can lead to a considerable overall temperature increase, especially for reheat impulses. This temperature is, however, still below 60°C. The distortion caused by heat input is neglectably low and in many cases hardly even measurable.
8. Tensile Strength

Welding widths of between 1.5 and 2.0 mm are generated during annular projection welding. For judgement calculations, we can operate with an average welding widths of 1.8 mm. The welded area is proportional to the diameter and the welding widths. The tensile force is proportional to the welded area and to the tensile strength of the weaker material.

\[ F = A \times R_m \]

- \( F \) = Tensile force of the weaker material
- \( A \) = Welded area in \( \text{mm}^2 \)
- \( R_m \) = Tensile strength of the material in \( \text{N/mm}^2 \)

Characteristic line „tensile force“

![Characteristic line "tensile force"

\[ 
\begin{align*}
640 \, \text{N/mm}^2 & \quad 480 \, \text{N/mm}^2 \\
320 \, \text{N/mm}^2 & \\
\end{align*}
\]

\( \text{Zugkraft } F_z \) (kN)

Ringbuckel \( \phi d_1 \) (mm)
(Schweißbreite 1,8mm)
Example:

Tensile force of the weaker material: \( R_m = 480 \text{ N/mm}^2 \)
Diameter of annular projection: \( \varnothing = 70 \text{ mm} \)
Width of welded area: \( b = 1.8 \text{ mm} \)

\[
F = A \times R_m
\]
\[
A = \varnothing \times \pi \times b
\]
\[
A = 395.6 \text{ mm}^2
\]

\[
F = 395.6 \text{ mm}^2 \times 480 \text{ N/mm}^2
\]
\[
F = 189,907 \text{ N}
\]
\( F \gg 190 \text{ kN} \)

9. Torsion Resistance

A judgement calculation of torsion resistance can be carried out on the basis of the welding width \( b \), the annular projection diameter \( d_1 \), and the tensile strength \( R_m \). The transversal strength \( T_z \), which is required for the calculation, can be taken from the table “Permitted Tensile Forces for Machine and Equipment Construction”. The values in this table are given for permanent, increasing or changing loads with a ratio of 3:2:1. The values in the table contain a 3-4-fold safety factor, considering influences such as notch effects and shaping.

\[
M_i = T_z \times A_u \times 2b
\]
\( M_i = \text{torque in Nmm} \)
\( T_z = \text{admissible transversal force in N/mm}^2 \)
\( A_u = \text{circular area surrounded by the annular projection mm}^2 \)
\( b = \text{welding width in mm} \)

In the example with a tensile strength of 480 N/mm², the “Table for Machine and Equipment quotes a value of approx. 120 N/mm² for the permitted transversal force under permanent load. For this tensile force, this results in the characteristic line between annular projection diameter \( d_1 \) and torque \( M_i \) as illustrated below. The characteristic line changes in proportion to the tensile force \( T_z \).

Example (120 N/mm²) for permanent load:
Annular projection diameter = 70 mm, torque = 1,660 Nm

Practice has shown that the torque is higher by factor 4 in a destructive test.

Example (80 N/mm²) for increasing load:
Annular projection diameter = 70 mm, torque = 1,108 Nm
The torsion resistance is influenced positively if the annular projection is positioned as far to the outside as possible, so that no notch is formed at the edge.
10. Welding quality for annular projections

The welding width has to be higher than the theoretical width, which results out of the geometry of the projection and the setting way.

For dynamic stressed parts the effective width „b2“ should be higher than 1.5 mm.

Before welding:

After welding:

\[ b_1 = \text{theoretical welding width} \]
\[ b_2 = \text{effective welding width} \]
\[ b_2 > b_1 \]

Revolving the width should have a minimum of „b1“. In the welded joint the faults in the bond must be lower than < 10%. Inside of the theoretical welding width „b1“ no cracks may occur.

Through try outs the heat penetration depth „s“ is empirical to determine. This measurement is to document. The heat penetration depth „s“ is a measurement for a constant energy input.