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Group standard **VW 60307**

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Electrical Connections

Ultrasonic Welding on Stranded Conductors

Requirements for and Testing of Copper Weld Nodes

Previous issues

VW 60307: 1998-11, 2002-08, 2004-10, 2005-05

Changes

The following changes have been made to VW 60307: 2005-05:

a) Standard completely revised, expanded, and restructured
b) General basic principles regarding the joining method incorporated
c) Specifications for conductors with reduced cross sections added
d) Specifications for the evaluation of weld nodes with a conductor cross section A_L> 30 mm^2 added
e) Qualification and release definitions added
f) Revision record in "Earlier issues" corrected.

Contents

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1 Scope

This standard defines the requirements for cable connections for cables with copper stranded conductors, as well as the corresponding testing. This standard defines the geometric and mechanical/technological properties of weld nodes joined with ultrasonic welding.

2 Definitions

Amplitude

The biggest lengthening of the sonotrode vibration, expressed as the ratio to the maximum amplitude defined by the design

Node variant

Node configuration with differences in number, cross section, structure, and materials between the cables being connected

Pressing dimension

Position of the anvil after it presses the inserted cable ends together after the welding tools are closed

Welding pressure

Pressure used to generate the contact pressure with which the anvil acts, during pre-compressing and welding, on the conductors being welded

Welding energy

Energy that must be introduced into the weld nodes

Weld node

Permanent electrical and mechanical connection between various cable ends between stranded cables.

Welding dimension

Position of the anvil after the specified welding energy has been introduced into the node and the welding operation is completed

Welding time

The time that the ultrasonic waves act on the material being welded until the required welding energy has been introduced into the weld node

Special node

Node with a harder pressing dimension check or node structure not described in this standard and for which individual tests as per table 3 are required

3 Symbols

A	Welding area
A_i	Actual conductor cross section of the individual stranded conductors
A_K	Effective weld node cross section
a_{KiF}	Distance between node insulation and permanent bending point
A_C	Cable cross section
a_p	Effective length of anti-peeling protection element
a_{vK}	Distance between connected nodes
A_0	Total actual cross section (actual cross section)
b_G	Flash width
b_K	Node width
C	Degree of compression
C_{mk}	Machine capability index
d_i	Diameter of an individual strand in a stranded conductor
D_U	Diameter of the circumscribed circle of the cable insulation
F	Contact pressure
F_B	Bending force
F_{pe}	Peeling force
F_{pu}	Tensile force
h_{eff}	Effective node height
h_G	Flash height
h_K	Node height
h_{Km}	Measured node height
K	Correction value for the node surface
L	Measuring device width
l_a	Length of weld stop zone
$l_{a, ALi}$	Distance between welding area and cable insulation
l_D	Strand end projection
L_i	Conductor i (i = 1, 2, etc.)
l_P	Length of evidently melted or joined cable insulation
l_s	Length of welding zone
l_T	Length of fused-on cable insulation
l_V	Length of insulation connection reinforcement with duct tape or heat-shrink tubing
M	Center of weld node
n_i	Number of strands in a stranded conductor i (i = 1, 2, etc.)
P	Welding power

s	Welding dimension
T_o	Upper exposure temperature
T_u	Lower exposure temperature
t	Time
t_o	Time of exposure with temperature T_o
t_u	Time of exposure with temperature T_u
x	Deviation as a percentage
α	Loose strand angle

4 Abbreviations

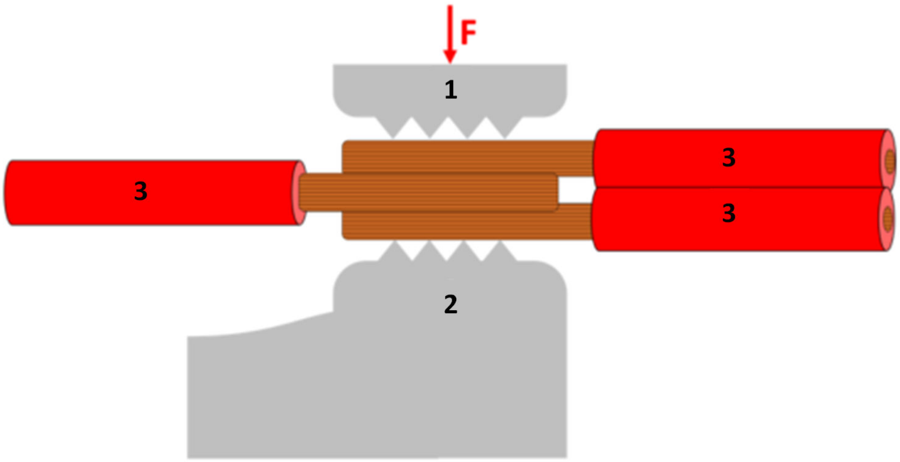
BMG	Build sample approval
BTV	Part owning developer, e.g., at Volkswagen/Audi, who owns the semi-finished product (yard goods) or assembled cables
HyperKVS	Engineering Data Management System (Volkswagen system)
KSK	Customized wiring harness
Q matrix	Qualification matrix

5 Basic principles for making weld nodes

5.1 Ultrasonic welding

The stripped ends of vehicle cables are permanently connected to each other with mechanical vibration energy and the simultaneously acting contact pressure; see figure 1.

The sonotrode's deflection with a specific amplitude causes the parts being welded to undergo high-frequency relative motion under relatively low pressure. Much like with diffusion welding, the material at the contact surfaces is welded in the solid phase and, in the case of materials with an identical structure, a crystalline joint will be formed there. The welding is homogenous and results in both high strength and excellent electrical conductivity. Structural changes in the parent material occur only in a very small area; the rest of the part keeps its structure and basic strength.



Legend

F	Contact pressure
1	Anvil
2	Sonotrode
3	Cable

Figure 1 – Schematic diagram of ultrasonic welding

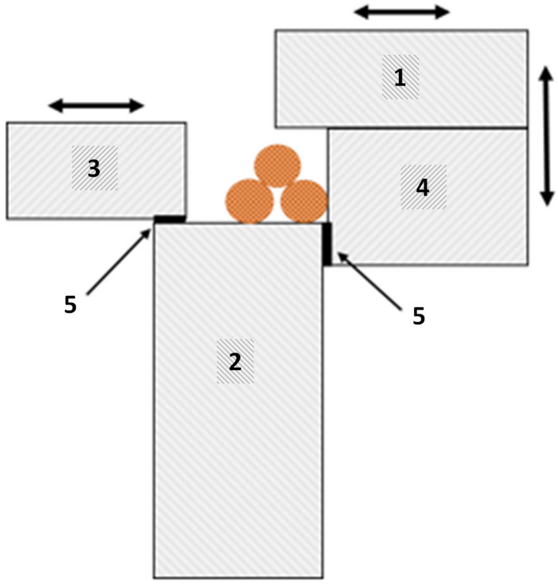
The operating frequency and output power of the ultrasonic generator are determined by the design and are not adjustable.

An operating frequency outside of the human hearing range is selected for ultrasonic welding. 20 kHz and 35 kHz are usual frequencies.

5.2 Welding tools and characteristic sizes

5.2.1 General mode of operation

Together with the surface plate (anvil plate) and side slide, the anvil and sonotrode welding tools form a four-sided closed compression space; see figure 2.



Legend

1	Anvil
2	Sonotrode
3	Side slide
4	Surface plate
5	Gap

Figure 2 – Schematic diagram of welding tools with direction of motion

5.2.2 Sonotrode and anvil

In order to allow for the low-loss transmission of sound energy, the anvil (counter surface) and the sonotrode (active tool) have a tool profile structure on their surface.

The anvil is used to apply the contact pressure to the material being welded and the welding motion is transmitted by the sonotrode. The amplitude of the sonotrode movement is controlled or set electronically.

The sonotrode and the anvil are wear parts. The durability of the sonotrode and the anvil is influenced to a large degree by the stress placed on them as a result of the structure of the nodes being welded, among other factors.

5.2.3 Side slide and surface plate

The distance between the side slide and surface plate determines the node width. In order to be able to adjust the welding space width in line with the node size, the side slide is adjustable. Together with the anvil's contact pressure, which can be varied, this makes it possible to achieve identical surface pressure conditions for all node variants and sizes.

The side slide and the surface plate are wear parts.

5.2.4 Gap size

The gap size between the sonotrode and the surface plate, as well as between the sonotrode and the side slide, is required in order for the sonotrode to be able to freely move for welding. However, excessively large gap sizes will result in strands undesirably migrating into them; see also the flash formation information in section 5.5.3.

5.2.5 Insertion aid

5.2.5.1 General information

In order to mix the cable ends being welded together in a targeted manner, an insertion aid may be required in order to ensure ideal welding between the cable ends.

5.2.5.2 Triangular or mixing insertion aid

A triangular or mixing insertion aid is a special tool that makes it possible to weld the conductor ends together on top of each other; see figure 3

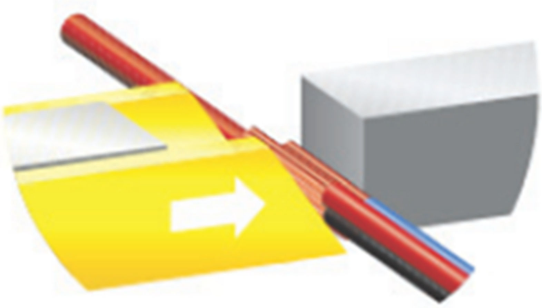


Figure 3 – Triangular or mixing insertion aid

5.2.5.3 Side slide for pre-adjustment

The side slide is already moved forward to the welding and node width before the welding operation and before the cable ends are inserted. This reduces the insertion area and minimizes the risk of cable ends being inserted next to each other; see figure 4.

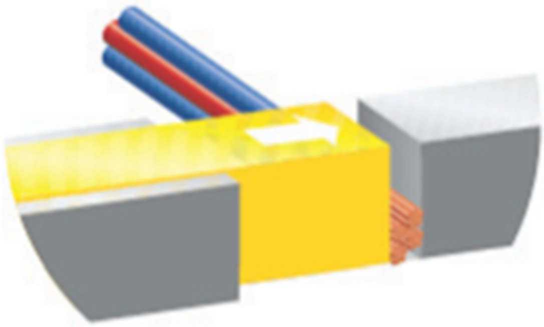


Figure 4 – Pre-adjustment with side slide

5.3 Welding process

5.3.1 Procedure

The flowchart in figure 5 shows the steps in the welding process.

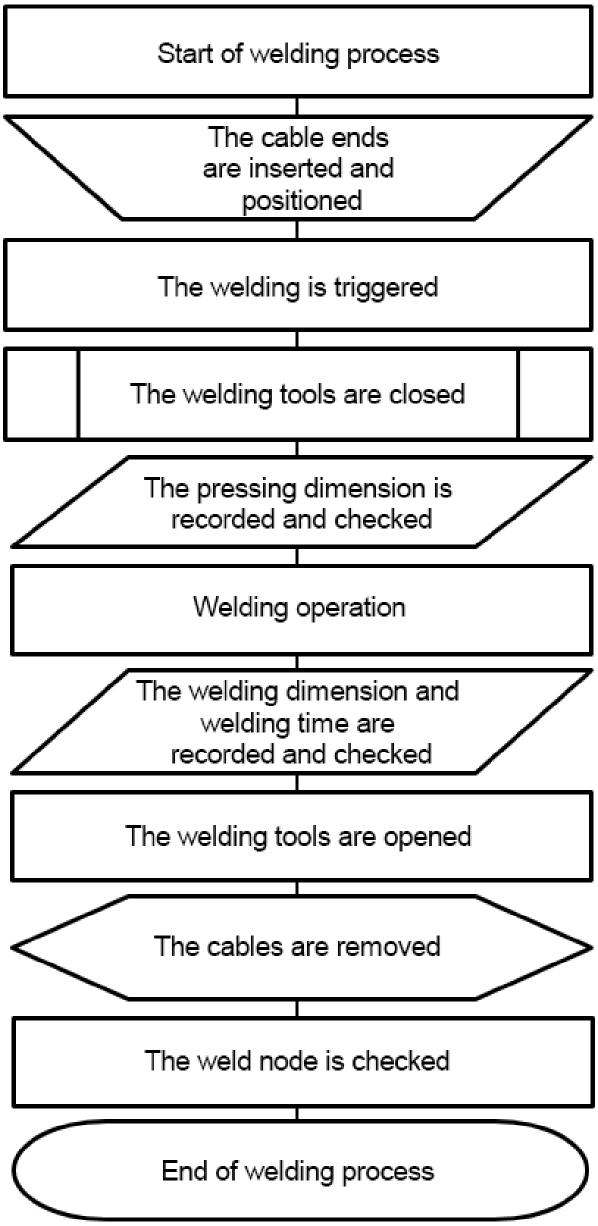


Figure 5 – Welding process steps

5.3.2 Cable end insertion and positioning

5.3.2.1 Procedure

The stripped ends of the cables being joined are placed inside the compression space. After the welding process starts, the anvil moves out of its side parking position.

Good positioning is characterized by the conductor end terminating flush with the welding profile edges or a comparable, optional stranded conductor stop; see figure 6.

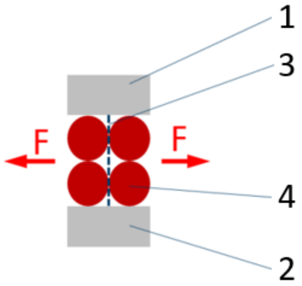
Figure 6 – Correct position of cable ends

5.3.2.2 Possible insertion errors

The following insertion and positioning errors are possible:

1. Side splices

   Side splices may be produced particularly when there is an even number of conductor ends with the exact same cross section. These side splices are unable to effectively absorb normal forces F; see figure 7.



Legend

F	Force normal to side splice
1	Anvil
2	Sonotrode
3	Side splice
4	Conductor

Figure 7 – Side splices

2. The positioning is not correct; see figure 8 and figure 9.

Figure 8 – Cable end not inserted sufficiently

Figure 9 – Cable end inserted too far

3. The insulation was inserted as well.

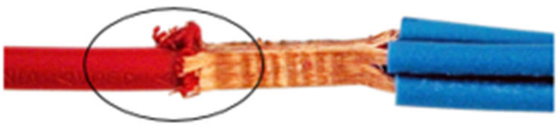


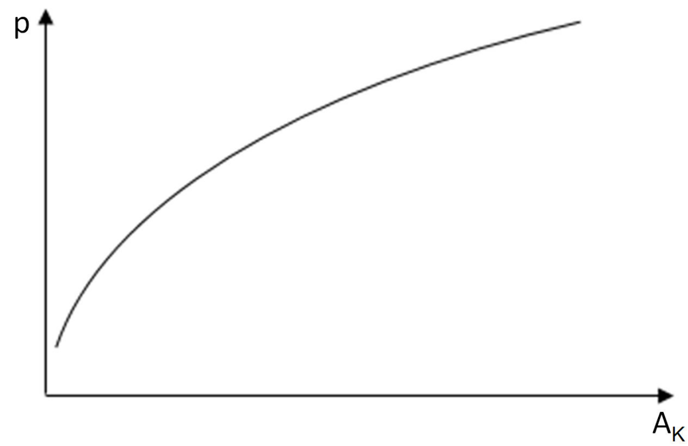
Figure 10 – Cable insulation in weld node

4. The wrong cable(s), or the wrong number of cables, were inserted.

5.3.3 Pressing dimension recording and check

After the welding tools are closed, the anvil will press the inserted cable ends together. The resulting anvil position is referred to as the "pressing dimension."

The desired value for the pressing dimension depends on the node variant (see figure 11), the anvil and sonotrode positions, and the defined closing force.



Legend

A_K Weld node cross section
p Pressing dimension

Figure 11 – Pressing dimension as a function of node cross section

5.3.4 Welding operation

If the pressing dimension matches the desired value, the welding operation will be started automatically: The welding power (see section 5.4.2.2) will be applied during the welding time (see section 5.4.3.2) under the welding pressure (see section 5.4.2.1) and the welded joint will be made.

The welding operation will end when the specified welding energy has been introduced into the node. The resulting anvil position is referred to as the "welding dimension."

5.3.5 Welding dimension and welding time recording and check

The welding dimension and welding time determined after the welding operation must be compared with the corresponding reference values in order to verify the degree of energy input.

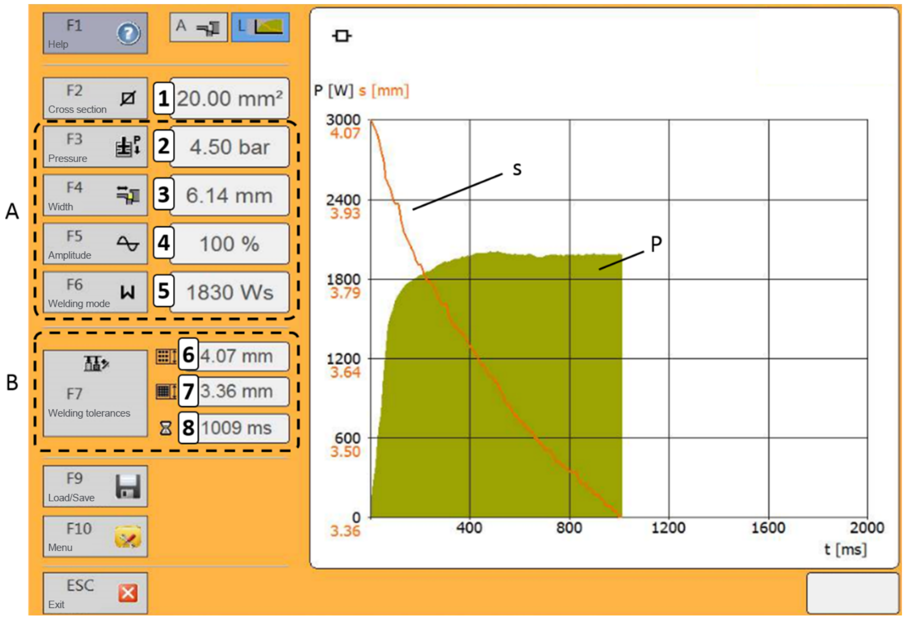
A certain part of the introduced welding energy is always converted to heat. The bigger the node size, the bigger the thermal load on the cable insulation. The requirements in section 6.5.5 apply.

5.4 Welding parameters

5.4.1 General information

In order to ensure consistent welding quality, the required welding parameters for each node variant are verified as per the qualification matrix (see section 8) and saved (see section 6.2).

The starting parameters are stored in the machine controller by cross section and are adjusted in line with the mechanical requirements (see section 7.1) if necessary; see figure 12.



Legend

P Welding power
s Welding dimension
t Welding time

Figure 12 – User interface for the machine controller (example) showing the adjustable welding parameters (A) and the resulting welding parameters (B) as per table 1

Table 1 – Welding parameters from figure 12

No. in figure 12	Welding parameters	
	Adjustable (A)	Resulting (B)
1	Cross section	—
2	Welding pressure	—
3	Weld width	—
4	Amplitude	—
5	Energy	—
6	—	Pressing dimension
7	—	Welding dimension
8	—	Welding time

5.4.2 Adjustable welding parameters

The welding parameters (see section 5.4.2.1 to section 5.4.2.4) must be set in a node-specific manner.

5.4.2.1 Amplitude

The amplitude has a large effect on the degree of compression (see section 5.6.2) and must be kept constant for all the welds for a node variant.

Unit: Absolute value in micrometers (µm) or as a percentage (%)

5.4.2.2 Welding pressure

The contact pressure resulting from the welding pressure must be defined in a node-specific manner and significantly affects the degree of compression (see section 5.6.2). It is controlled or set electronically.

Unit: bar (for pneumatic anvil drives; different for alternative drives)

5.4.2.3 Welding energy

The welding energy must be defined in a node-specific manner and significantly affects the degree of compression.

The welding energy (green area in figure 12) is the integral of the welding power over the welding time.

Unit: Watt seconds (Ws)

5.4.2.4 Weld width

The weld width determines the later weld node width. The weld width must be specified based on the total weld node cross section. For this purpose, the side slide moves to the set position and, together with the sonotrode, anvil, and surface plate, forms the welding space (see also section 6.5.4).

Unit: Millimeters (mm)

5.4.3 Resulting welding parameters

5.4.3.1 General information

The adjustable welding parameters result in the following in a node-specific manner: Pressing dimension (see section 5.3.3), welding dimension (see section 5.3.5), and welding time (see section 5.4.3.2).

5.4.3.2 Welding time

The welding time serves as the check dimension for process monitoring. The reference value for the welding time is defined when calibrating the node variant (making the reference node) (see section 6.2).

Unit: Milliseconds (ms)

5.5 Weld node[1)]

5.5.1 Weld node types

5.5.1.1 Connecting node

In connecting nodes, cables terminate in two directions; see figure 13.

Figure 13 – Connecting node (side view)

5.5.1.2 Terminal node

In terminal nodes, call cables terminate in one single direction; see figure 14.

Figure 14 – Terminal node (side view)

5.5.2 Node size/total cross section

5.5.2.1 General information

The nominal size of the weld node is the total of the nominal cross sections of the conductors being welded.

The width of the weld node is determined or influenced by the distance between the side slide and the surface plate (see section 5.2.3). The height of the weld node is determined or influenced by the welding parameters (see section 5.4).

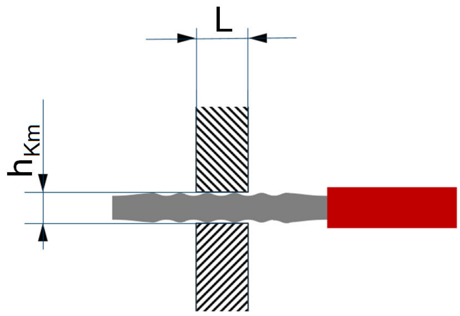
The welding dimension (see section 5.3.5) is not necessarily the same as the measurable or effective node height.

5.5.2.2 Measurable node height

The weld node's surface is significantly shaped by the welding tool's ripple structure. Accordingly, the measurable node height is measured using at least two wave peaks (see figure 15). Weld node flash must not be included in node dimension measurements, and must be removed if necessary.

The measurable node height is evaluated as per the qualification matrix (see section 8).

1) Weld nodes are also referred to as splices.



Legend

h_{Km}	Measured node height
L	Measuring device width (e.g., caliper)

Figure 15 – Measuring the node dimensions

5.5.2.3 Effective node height

As per formula (1), the effective node height takes into account the node surface structure (tool impression) and is required in order to determine the degree of compression (see section 5.6.2):

$$h_{eff} = h_{Km} - K \qquad (1)$$

Legend

h_{eff}	Effective node height
h_{Km}	Measured node height
K	Correction value for the node surface[2)]

5.5.2.4 Node width

The node width (see dimension B in figure 17) is required in order to determine the degree of compression (see section 5.6.2).

5.5.2.5 Node length

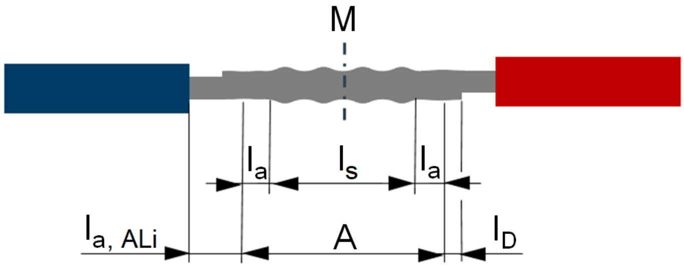
A distinction must be made between weld stop zones and welding zones when it comes to the node length and to the welding area length.

The sonotrode and anvil weld stop zones are optimized in terms of mechanical node requirements.

The length of the welding area is an anvil-specific and sonotrode-specific dimension.

The node geometry is verified as per figure 16 starting from the center of the sonotrode and anvil impressions on the weld node (sonotrode center):

2) K = 0,2 mm, unless otherwise specified.



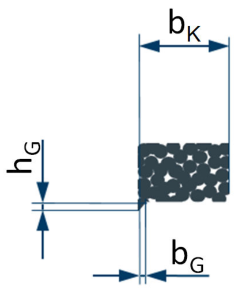
Legend

A	Welding area (sonotrode width dimension)
l_a	Length of weld stop zone
$l_{a, ALi}$	Length of weld stop zone between welding area and cable insulation
l_D	Strand end projection
l_s	Length of welding zone
M	Center of weld node

Figure 16 – Node length

5.5.3 Flash

Flash may form at the edges of the weld node due to the gaps between the sonotrode, surface plate, and side slide.



Legend

b_G	Flash width
b_K	Weld node width
h_G	Flash height

Figure 17 – Flash on weld node

Requirements as per section 6.5.6 and qualification matrix (see section 8).

5.6 Joint characteristic values

5.6.1 Height-width ratio

The ultrasonic welding process makes it possible to introduce the welding energy only from one boundary surface of the rectangular joint. The node-width-to-node-height ratio has a large influence on the energy penetration into the material being welded.

The height-width ratio specifications apply (see section 6.5.4).

5.6.2 Degree of compression

Welding under an acting force means that the node is compressed, i.e., the strands will be deformed and the spaces between the strands will be made significantly smaller.

The degree of compression is defined as the ratio of the total actual conductor cross sections to the effective node cross section; see formula (2).

Degree of compression

$$C = \frac{A_0}{A_K} \times 100\ \% \qquad (2)$$

Legend

A_K	Effective node cross section
A_0	Total actual cross section (actual cross section)
C	Degree of compression

The total of the actual conductor cross sections of the stranded conductors forming the node is calculated as per formula (3):

$$\sum_{i=1}^{m} A_i = A_1 + A_2 + A_3 + \cdots + A_m \qquad (3)$$

Legend

A_i	Actual cross section of individual conductor

The individual actual conductor cross sections are calculated as the total of the strand cross sections of the stranded conductor as per formula (4):

$$A_i = n_i \times \frac{\pi}{4} d_i^2 \qquad (4)$$

Legend

A_i	Actual conductor cross section of the stranded conductor
d_i	Diameter of an individual strand
n_i	Number of strands

The effective node cross section is calculated as per formula (5) using the effective node height and the node width; see also figure 17.

$$A_K = b_K \times h_{eff} \qquad (5)$$

Legend

A_K	Effective node cross section
b_K	Node width
h_{eff}	Effective node height

6 Requirements

6.1 General information

The weld node quality can be measured with nondestructive methods only if certain conditions are met. The requirements defined in section 6.2 to section 6.6 must be met in order to ensure that the weld node properties will be maintained under economically feasible production conditions.

The requirements must be checked as per the qualification matrix (see section 8).

6.2 Welding machine

The welding parameters (see section 5.4) are stored as starting parameters in the welding machine's software. Automatic process monitoring and energy control is required.

The welding jig must be adequate for the weld nodes being made in terms of the following characteristics:

- Compression space
- Welding power
- Error detection

The weld width setting must be reproducible in a sufficiently precise manner and must not be changed by external influences.

Timely tool maintenance (see section 6.3.4.5) must be ensured based on the number of welding operations or a comparable metric.

Using node-specific welding parameters for identical machine models is permissible only if the machine and tool manufacturing tolerances are effectively compensated for with suitable calibration. The manufacturer's specifications must be observed.

Every time after welding machines are set up again or relocated, test welds and tests as per the qualification matrix (see section 8) are required.

Repairs and maintenance work must be carried out exclusively by trained and authorized personnel. The manufacturer's specifications must be observed.

A C_{mK} of 1,67 must be verified for the capabilities required as per the qualification matrix (see table 5).

6.3 Process monitoring

6.3.1 General information

The monitoring criteria are the welding time (see section 5.4.3.2), the pressing dimension (see section 5.3.3), and the welding dimension (see section 5.3.5).

In order to ensure reliable error detection, the measuring system resolution must be at least 0,01 mm.

6.3.2 Insertion position

The cable ends must be straight and as parallel to each other as possible. It must be ensured that no strands stick out.

The stranded conductors with the largest strand diameters must be placed on the side facing the sonotrode (see section 5.3.2). Due to practical considerations, cables with the largest insulation outer diameter can be inserted on the sonotrode side after a corresponding check.

If necessary, an insertion aid (see section 5.2.5) must be used.

The cables' insulation ends must be positioned identically with suitable measures. The weld node insulation requirements in the wet area (see section 6.6.5.3) must be met.

If an insertion error is detected (see section 5.3.2.2), it must not be possible to run the welding operation.

6.3.3 Pressing dimension and welding dimension

Insertion errors that result in a change in height (see section 5.3.2) and a deviation percentage x from weld node cross section A_K must be detected by the machine controller. The following applies to x within this context:

– x = 7% if weld node cross section $A_K < 5\ mm^2$

– x = 5% if weld node cross section $A_K \geq 5\ mm^2$

In order to reliably detect when there are missing cables, the smallest conductor cross section must be at least 9% (if $A_K < 5\ mm^2$) or 7% (if $A_K \geq 5\ mm^2$) of the total cross section.

The pressing dimension (see section 5.3.3) must be determined during the process for each weld and compared with the verified desired value.

The welding operation is allowed to be started again after the cause behind a pressing dimension error is fixed, but no more than three times.

6.3.4 Welding operation

6.3.4.1 General information

If the node height or anvil position expected in the tolerance range cannot be reached within the maximum permissible welding time (see section 5.4.3.2), the welding operation must be aborted. These nodes are not allowed to be rewelded and must be reliably removed from the production process. It is permissible to strip and weld the cable ends again under consideration of the cable's permissible minimum length. This length must be specified by the user.

After the welding operation, every node must be visually inspected for strands that are sticking out or have been squeezed out (see section 6.5.7). These strands must be removed under consideration of the permissible node cross section reduction (see section 6.3.3).

6.3.4.2 Welding time

The welding time (see section 5.4.3.2) is allowed to be continued, i.e., increased, in order to reach the required delivery of energy, but must not exceed the reference value by more than 15%.

6.3.4.3 Welding tool

In order to optimize the mechanical properties, notches must be effectively avoided in the tool profile's edge zones. This can be achieved, among other ways, with the use of weld stop zones in which the sonotrode and anvil surface ripple structure gradually disappears in the branch-off direction.

6.3.4.4 Gap size

The gap size (see section 5.2.4) must be set as per the machine manufacturer's or tool manufacturer's specifications.

6.3.4.5 Tool inspection interval

Unless otherwise defined, the wear parts (see section 5.2) must be checked at regular intervals. The first check must be after 50 000 welding operations at the latest, and 25 000 welding operations after that as per the qualification matrix (see section 8). The intervals must be adjusted in line with the requirements.

Wear parts must be replaced as per the machine manufacturer's or tool manufacturer's specifications (genuine parts by the manufacturer must be used exclusively).

6.3.4.6 Impurities

Impurities can negatively influence the weld properties and must be effectively prevented.

The condition of the tool surfaces must be carefully checked with each inspection; copper and dirt particles must be removed if necessary.

6.4 Cables

6.4.1 Materials and dimensions

The materials and dimensions of the cables being joined must conform to VW 60306-1 and VW 60306-4.

Welding tinned cable ends is impermissible.

6.4.2 Stripping

A standardized nominal strip length must be used within a weld node.

In general, the specifications in VW 60330 apply to stripping.

The strip length must be verified under consideration of the number and cross section of the individual conductors, the tool width, and other requirements for downstream processes (water leaktightness; see section 6.6.5.3).

6.4.3 Number of conductors

The number of conductors is limited as per table 2.

Table 2 – Maximum permissible number of conductors in weld node

Node variant	Node type	
	Terminal node	Connecting node
Standard node	≤ 7	≤ 5 per side
Node with harder pressing dimension check	8 to 15	6 to 8 per side; maximum total of 15

In the case of weld nodes with a large number of conductors, handling is more difficult and detecting insertion errors (see section 5.3.2.2) with a pressing dimension check is harder. These weld nodes must be qualified as special nodes as per the Q matrix in section 8. It must be checked whether suitable additional measures are required in order to ensure the correct conductor positioning.

The weld node insulation specifications (see section 6.6.5) must be observed.

6.4.4 Individual conductor combinations and cross sections

The required insertion check (see section 5.3.3) limits the usability of small individual conductor cross sections. Table 3 Lists the possible cross section combinations.

Table 3 – Permissible combinations (cross section jumps) of individual conductors

Cross section area in mm²

Conductor cross section A_{L1}	Conductor cross section A_{L2}									
	0,13	0,35	0,5	0,75	1	1,5	2,5	4	6	10
0,13	X	X	X	(X)	(X)	—	—	—	—	—
0,35		X	X	X	X	X	—	—	—	—
0,5			X	X	X	X	X	—	—	—
0,75				X	X	X	X	—	—	—
1					X	X	X	X	—	—
1,5						X	X	X	X	—
2,5							X	X	X	X
4								X	X	X
6									X	X
10										X

X Permissible combination
— Impermissible combination
(X) Individual check required

If the specified condition cannot be implemented in a single weld node, splitting the node into multiple connected weld nodes is required.

For the dimensioning of the cable between the nodes, the permissible current-carrying capacity of both weld nodes must be taken into account; the distances between these weld nodes must be maintained as per section 6.6.4.1.

The combination options for conductor cross sections that are not included in table 3 – especially intermediate cross sections (see VW 60306-1, "Thin-walled cable – Conductor structure, asymmetrical, stranded/flexible, type B" table) – must be evaluated as per the monitoring criteria (see section 6.3.3).

The individual check for special nodes must be carried out as per the qualification matrix (see section 8).

6.5 Weld node

6.5.1 General requirements

The anvil and sonotrode impressions must be clearly recognizable on the node surface in the welding area.

Cracks and fractures in the weld node are impermissible.

The individual conductors' insertion position must conform to section 6.3.2.

6.5.2 Strength values

6.5.2.1 Peeling and tensile strengths

In terms of the minimum requirements concerning strength, a distinction is made between the following reasons for testing: Capability testing, cable release, and tests during production

The joint quality is determined by measuring the pull-off or peeling force as per section 7.1.2 and section 7.1.3; for minimum values, see table 4.

Table 4 – Specifications for peeling and pull-off forces

Conductor cross section	Reason for testing/tests			
	Capability test		Cable release	Test during production
	Peeling force	Pull-out force	Peeling force	Peeling force
mm^2	N	N	N	N
0,13	5	50	12	10
0,35	12	50	24	15
0,5	15	60	30	19
0,75	23	85	46	29
1,0	35	140	55	44
1,5	45	150	65	56
2,5	70	200	110	88
4,0	100	310	160	125
6,0	130	450	200	163
10	150	500	230	188

Specifications for conductor cross sections not included in table 4 are interpolated for intermediate cross sections (see VW 60306-1, "Thin-walled cable – Conductor structure, asymmetrical, stranded/flexible, type B" table) and extrapolated for larger cross sections.

6.5.2.2 Flexural strength

Strands must not break at the transition point to the weld zone.

Strands must not loosen or become detached at the weld node.

The flexural strength must be tested as per section 7.1.4.

6.5.3 Voltage drop

The test must be carried out as per section 7.2.2.

The following maximum values are permissible for the voltage drop relative to a test current of 1 A:
- New condition: 0,01 mV
- After environmental test (see section 7.2): 0,05 mV

6.5.4 Height-width ratio

The weld node height-width ratio depends on the node size and is shown in figure 18. The node width is set by the machine controller based on the node cross section. The node height is a resulting welding parameter (see section 5.4.3). Accordingly, an exact height-width ratio does not make sense within this context.

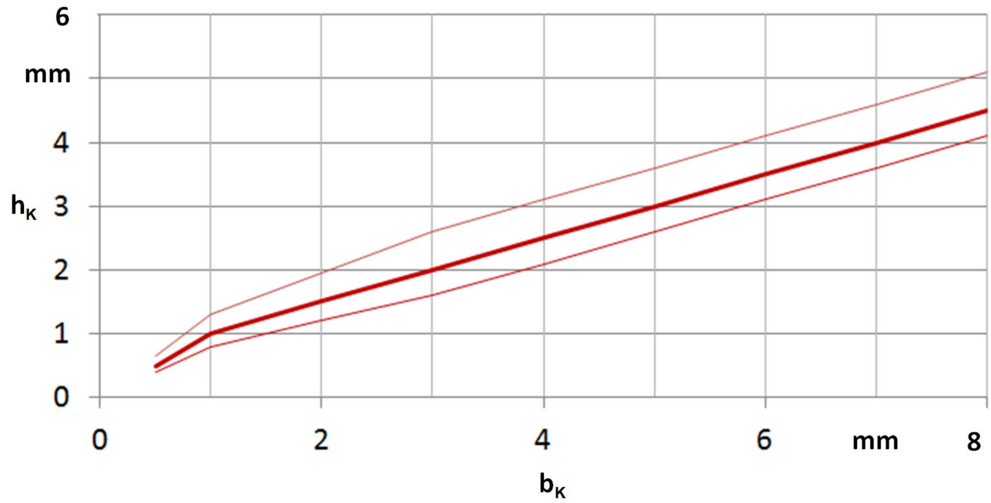


Figure 18 – Typical node height (h_K) to node width (b_K) ratio (thick line) with dispersion range

The height-width ratio for larger weld nodes must be extrapolated accordingly.

6.5.5 Thermal effect

6.5.5.1 Influence of node size

When welding, the production of heat is unavoidable. No special thermal effects are to be expected for node cross sections $A_K < 30\ mm^2$. Node cross sections $A_K \geq 30\ mm^2$ require a special evaluation of the thermal effects.

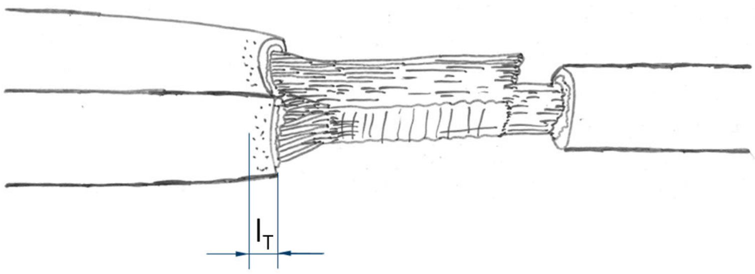
The thermal effects specified in section 6.5.5.2 to section 6.5.5.4 must be avoided or minimized as far as possible, but are not a quality characteristic.

6.5.5.2 Oxidation tints

If any oxidation tints are produced, the welding parameters and the condition of the sonotrode and anvil must be checked for wear and suitability.

6.5.5.3 Cable insulation fused on

Insulation aged as a result of heat is effectively supported mechanically during the node insulation process (see section 6.6.5). See figure 19.



Legend

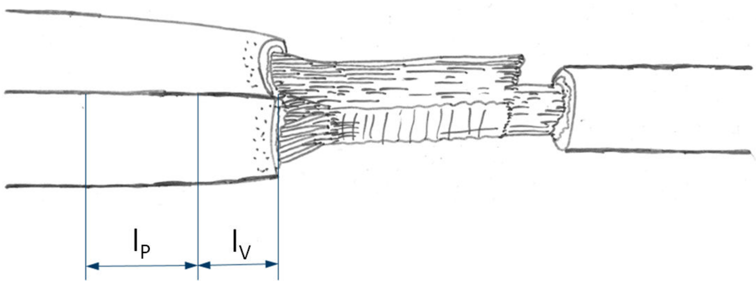
l_T Length of fused-on cable insulation

Figure 19 – Fused-on cable insulation

Fused-on cable insulation is permissible if l_T << 3 mm evidently.

6.5.5.4 Cable insulation elements melting together

Connections between different cable insulation elements can result between cables with the same branch-off direction as a result of the insulation materials melting; see figure 20.



Legend

l_P Length of evidently melted or joined cable insulation
l_V Length of insulation connection reinforcement with duct tape or heat-shrink tubing

Figure 20 – Cable insulation elements melted together

This connection must be reinforced with duct tape (see section 6.6.5.2) or heat-shrink tubing (see section 6.6.5.3) with a length l_P > 10 mm.

If the cables are evidently connected over a length l_V that is equal to or greater than the insulation diameter of the maximum individual conductor, the welding parameters and the condition of the sonotrode and anvil must be checked for wear and suitability.

6.5.6 Flash

Flash formation is an indicator of tool wear.

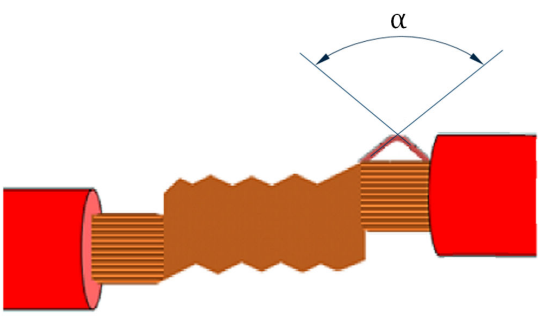
Even if the flash is not a quality characteristic, it must still be minimized effectively. The following dimensions as per section 5.5.3 must be adhered to.

– $b_G \leq 0{,}2$ mm
– $h_G \leq 0{,}5$ mm

6.5.7 Strands that are sticking out or have been squeezed out

Strands that are loose, have been squeezed out, or are sticking out are impermissible. They must be placed close to the rest, or removed under consideration of the permissible cross section reduction.

If there are snags even with the correct settings, these snags must be placed close to the rest. Flat loose strands, i.e., those with a loose strand angle $\alpha > 90°$, do not have to be placed close to the rest; see figure 21.



Legend

α Loose strand angle

Figure 21 – Strand squeezed out with the corresponding loose strand angle

6.5.8 Compression

All strands must be deformed and joined with each other; the individual strands must be recognizable in a transverse microsection.

The degree of compression must be verified with pull-out and peeling force tests as per the qualification matrix (see section 8).

6.6 Position of weld node in the wiring harness

6.6.1 General information

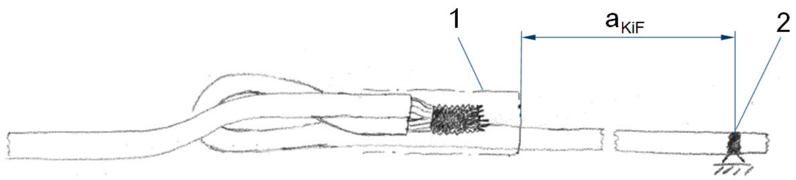
Fasteners (e.g., cable ties) must not be positioned on the electrical (see section 6.6.5) or mechanical (see section 6.6.6) weld protector.

When making wiring harnesses, the strength values that can be reached depending on the cross section must be taken into account with appropriate measures.

In particular for smaller conductor cross sections, there must not be any bending/redirection points, harness assembly pins, or other risks of mechanical loading in the area of weld nodes.

6.6.2 Minimum distance from permanent bend points

The wiring harness design must ensure that weld nodes are positioned in such a way that no external mechanical loads will act on the weld nodes in the corresponding installed condition. Distance a_{KiF} from permanent bend points must be at least 300 mm (see figure 22 and figure 23).

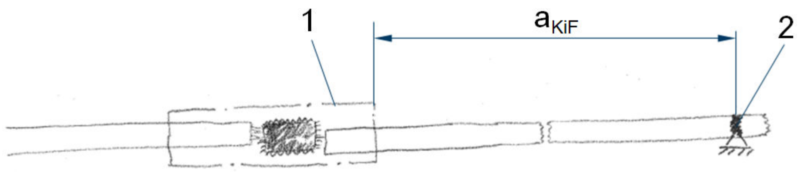


Legend

a_{KiF}	Distance between node insulation and permanent bending point
1	Node insulation
2	Permanent bending point (secured or bending point)

Figure 22 – Terminal node tied back (shown without the required securing element)

NOTE: Figure 22 shows the tied-back terminal node without the required securing element.



Legend

a_{KiF}	Distance between node insulation and permanent bending point
1	Node insulation
2	Permanent bending point (secured or bending point)

Figure 23 – Distance dimension for the connecting node

6.6.3 Minimum contact element distance

Contact elements can be loaded mechanically by welding energy transmitted by the cable. In all cases, at least the recommendation from the latest screening list documented in HyperKVS (see example in figure 24) must be adhered to. For contacts for which a minimum length is not specified in the screening list, the distance between the contact element and the weld node must be at least 400 mm.

Figure 24 – Example of screening list in HyperKVS

If the specified distance between the contact element and the weld node cannot be implemented with the design, only contact elements suitable for this situation are allowed to be used.

The suitability of the contact elements can be gathered from the supplementary component documentation (TDO) documented in HyperKVS under the corresponding part number (see example in figure 25).

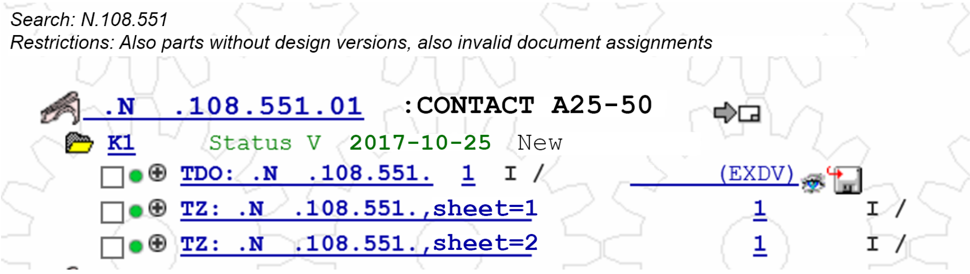
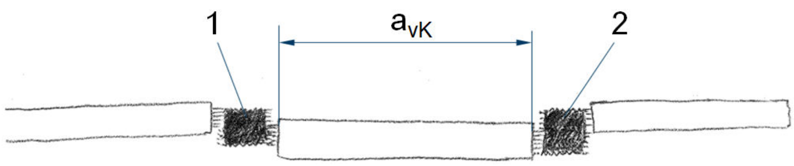


Figure 25 – Supplementary component documentation in HyperKVS using contact element N 108 551 as an example

6.6.4 Distances between weld nodes

6.6.4.1 Distances between connected weld nodes

If the permissible combination (see section 6.4.4) requires connected weld nodes, a distance a_{vK} of at least 60 mm is required between these weld nodes; see figure 26.



Legend

a_{vK}	Distance between connected nodes
1	Connected node 1
2	Connected node 2

Figure 26 – Distance between connected nodes

6.6.4.2 Distances for twisted cables

Distances in the case of twisted cables must be maintained as per the corresponding Performance Specification[3)].

6.6.5 Weld node insulation

6.6.5.1 General information

Weld nodes must be electrically insulated, as far as possible, immediately after welding before the next production step in order to effectively protect, in particular, weld nodes with small individual conductors from mechanical loading (see section 6.6.6).

3) See HyperKVS, LAH 000 900 AC.

6.6.5.2 Insulation for weld nodes in the dry area

Before a weld node is used in the dry area, the weld node must be insulated at least with coated duct tape as per VW 60360-1.

6.6.5.3 Insulation for weld nodes in the wet area

For the insulation for weld nodes in the wet area, heat-shrink tubing, e.g., with adhesive on the inside, must be used, and the requirements in VW 60360-3 must be observed[4)].

In the case of connecting nodes (section 5.5.1.1), the individual cables must be distributed in such a way that the circumscribed circles on both sides will have the same size as much as possible.

6.6.6 Mechanical protection for weld nodes

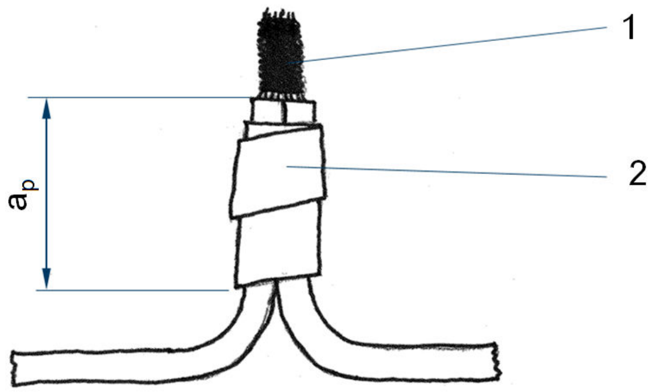
6.6.6.1 General information

Weld nodes must resist a mechanical peeling force of at least 45 N for wiring harness assembly.

If the mechanical strength (see table 4) is not verifiable with the individual cable joint, the finished wiring harness must be used to evaluate whether effective additional measures for mechanically protecting the weld node, e.g., anti-peeling protection element and securing with additional turn, are required.

6.6.6.2 Anti-peeling protection element

In order to protect the weld node from mechanical loads resulting from the cable being pulled, an anti-peeling protection element must be added for the cable ends as shown in figure 27. This anti-peeling protection element absorbs forces acting on this area and, in addition, prevents the weld node from having to absorb mechanical loads as a result of length balancing or excess cable lengths. The length of anti-peeling protection element a_p must be at least 50 mm.



Legend

a_p Effective length of anti-peeling protection element
1 Node
2 Anti-peeling protection element

Figure 27 – Anti-peeling protection element

The anti-peeling protection element must then be tied back as shown in figure 28.

4) For water-protected nodes, Test Specification PV 5507 is currently being developed.

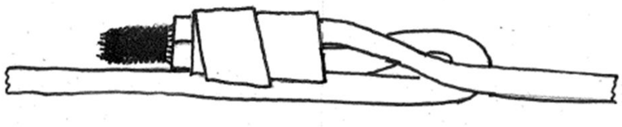


Figure 28 – Anti-peeling protection element tied back for pull relief (tied back terminal node shown without required securing element)

7 Tests

7.1 Mechanical tests

7.1.1 General information

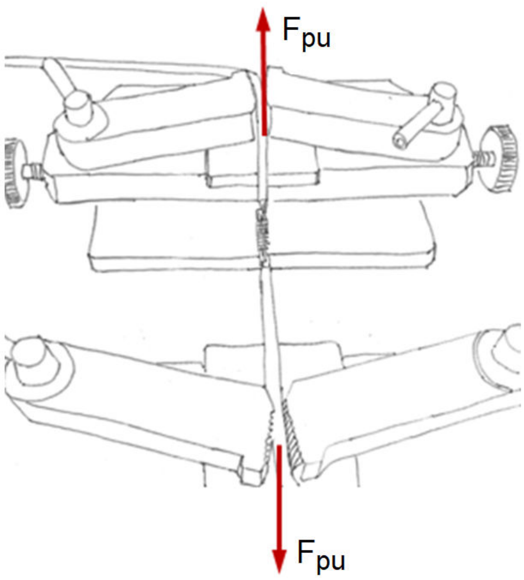
Tensile and peeling force tests as per DIN EN 60512-16-4 must be carried out with a speed of 50 mm/min.

7.1.2 Tensile force test

For a weld node type, the smallest nominal conductor cross section must always be tested. Weld nodes in which the strands of the conductor being tested lie against the anvil-side node surface must be selected.

The test samples must be used without weld node insulation (see section 6.6.5) and without mechanical protection (see section 6.6.6).

In order to avoid shearing forces, opposite conductors must be selected in such a way that the longitudinal axis of the node is parallel to the clamped cable ends; see figure 29.



Legend

F_{pu} Tensile force

Figure 29 – Tensile force test

The tensile force test must be carried out with the smallest possible node variant (see section 8.1.1.3.1).

The pull-out forces for pulling out the conductors from the weld node must reach the values defined in table 4.

7.1.3 Peeling force test

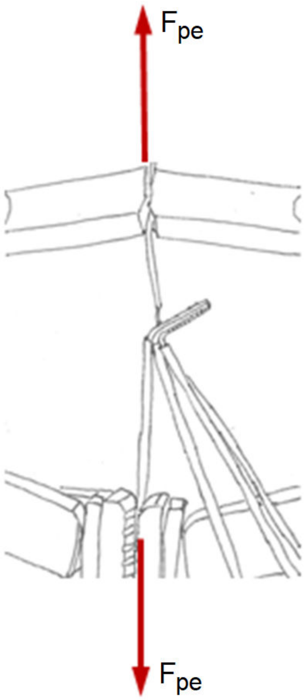
The peeling force test is carried out with different weld nodes for the various test objectives in the qualification matrix (see section 8).

For a weld node type, the smallest nominal conductor cross section must always be tested. Weld nodes in which the conductor being tested lies against the anvil-side node surface must be selected. The test setup is shown in figure 30.

The test samples must be used without weld node insulation (see section 6.6.5) and without mechanical protection (see section 6.6.6).

If the peeling force test reveals that the tested conductor was significantly covered by other conductors, this measured value cannot be used and the measurement must be repeated.

The nominal cross section of the opposite conductor must at least be as large as that of the conductor being tested. If necessary, multiple conductors can be grouped together.



Legend

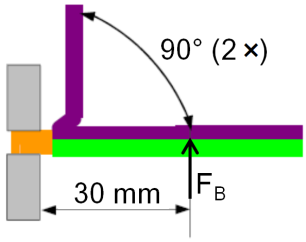
F_{pe} Peeling force

Figure 30 – Peeling force test

The peeling forces for peeling the conductors from the weld node must reach the values defined in table 4.

7.1.4 Bend test

The weld node cables on top on the anvil side must be bent back up 90° and then back to the original position twice. The weld node is secured in place and the force is applied to the cables being tested at a distance of 30 mm from the weld node.



Legend

F_B Bending force

Figure 31 – Bend test

The bend test must be carried out with the following node variants:

- Smallest possible node cross section (see section 8.1.1.3.1)
- Medium node cross section (see section 8.1.1.3.2)
- Largest possible node cross section with smallest number of conductors (see section 8.1.1.3.3)
- Largest possible node cross section with largest number of conductors (see section 8.1.1.3.4)

The flexural strength requirements in section 6.5.2.2 must be met.

7.2 Environmental test

7.2.1 Test sequence

The following test sequence must be followed:

1. Initial visual inspection
2. Initial voltage drop test (see section 7.2.2)
3. Temperature shock loading (see section 7.2.3)
4. Damp heat loading
5. Thermal loading
6. Final voltage drop test (see section 7.2.2)
7. Final visual inspection
8. Peeling force test (see section 7.1.3)

7.2.2 Voltage drop

The voltage drop test as per DIN EN 60512-2-1 is carried out as per figure 32.

In order to ensure a robust measurement, the test current density is 5 A/mm^2; the value for the smaller nominal cross section must be used if there are various cross sections.

The voltage drop across the weld node is calculated by subtracting the individual voltage drops of the conductors between points A/B and C/D from the total voltage drop between points A/D.

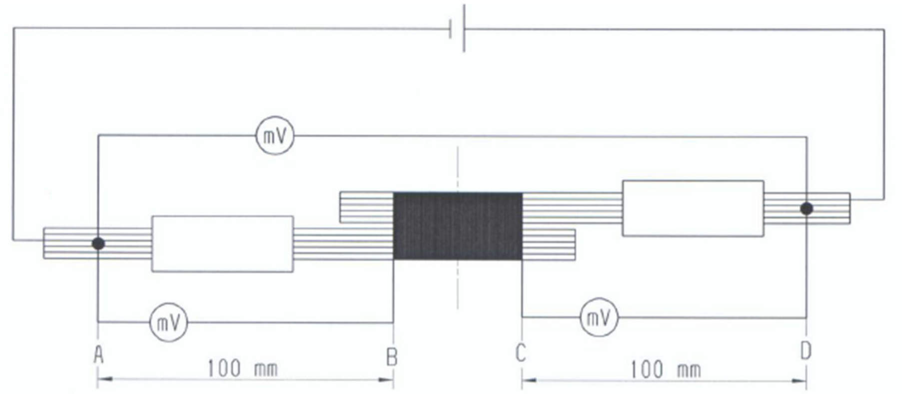
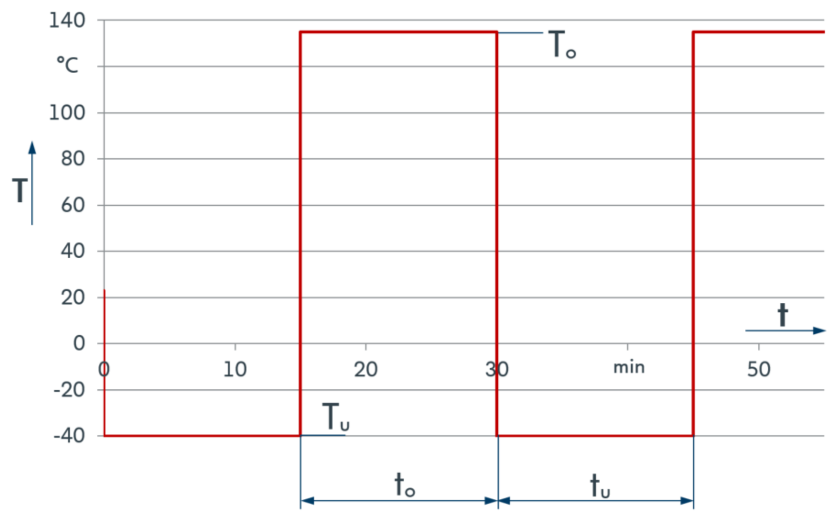


Figure 32 – Test setup for measuring the voltage drop

7.2.3 Temperature shock loading

144 cycles as per figure 33 must be performed.



Legend

T_o	Upper exposure temperature (135 °C)
T_u	Lower exposure temperature (-40 °C)
t_o	Time of exposure with T_o (15 min)
t_u	Time of exposure with T_u (15 min)

Figure 33 – Temperature shock cycle

The acclimatization period from T_u to T_o must not exceed 10 s.

7.2.4 Damp heat loading

In order to test loading with damp heat, 7 cycles in the condensation atmosphere with alternating humidity & air temperature (AHT) as per DIN EN ISO 6270-2 must be carried out.

7.2.5 Thermal loading

The thermal stability must be tested 168 h at 105 °C in the forced air oven.

8 Release/qualification

8.1 Release tests

8.1.1 Capability tests

8.1.1.1 Qualification cases

Capability tests must be carried out in the following qualification cases:

Type release (machine type release), machine capability and inspection (see table 5), node release for special nodes (see table 7), and cable release for build sample approval (BMG)/production release (see table 8).

The requirements as per table 4 must be met.

8.1.1.2 Node variants

8.1.1.2.1 Manufacturability test and initial release

An initial release is required for all individual node variants (individual nodes and production nodes). Within a company group, it is allowed to use the release verification from other locations if the machine type and semi-finished product (yard goods) are identical.

Initial releases for special nodes and after making parameter adjustments (see qualification matrix in table 7) must be location-specific.

8.1.1.2.2 Individual node variant/shop order release

The test must be carried out as per the order configuration, i.e., on the node variants required for a wiring harness being produced.

8.1.1.2.3 Typical individual node

As a typical individual node, a weld node that represents the general machine capability must be tested.

The characteristic feature is an identical node structure with a large batch size.

The cable manufacturer defines a release node for checks after maintenance or during inspection.

8.1.1.2.4 Boundary samples for the typical individual node

The smallest weld node and the largest weld node in the lower and upper cross section ranges of the machine type must be tested. The cable manufacturer defines the test for the node configuration.

8.1.1.2.5 Typical production node

The characteristic feature is a varying node structure with a small batch size, usually welded in sequence.

The cable manufacturer defines the weld node that must be tested.

8.1.1.3 Node cross sections

8.1.1.3.1 Smallest possible node cross section

The smallest node cross section of the machine process range (e.g., 3 × 0,13 mm^2) must be tested.

8.1.1.3.2 Medium node cross section

30% of the total cross section of the largest possible node cross section must be tested as per section 8.1.1.3.3 and section 8.1.1.3.4.

8.1.1.3.3 Largest possible node cross section, smallest number of conductors

The largest node cross section of the machine process range must be tested for continuous operation testing. The node structure has as few individual conductors as possible.

8.1.1.3.4 Largest possible node cross section, largest number of conductors

The largest node cross section of the machine process range must be tested for continuous operation testing. The node structure has as many individual conductors as possible.

8.1.2 Preparation tests

Calibrating production releases and weld nodes (making reference nodes), using adjusted welding parameters as per the specifications in the qualification matrix in table 7; specification values as per table 4.

8.1.3 Cable release

The requirements as per table 4 must be met.

Process verification as per table 8 must be carried out for the cable release.

8.1.4 Test during production

The specification values in table 4 apply to tests during production.

8.2 Qualification matrix

The requirements must be verified with different scopes depending on the specific situation and as per the specifications in table 5 to table 9.

Table 5 – Qualification matrix for machine release

<table>
<tr><th colspan="2" rowspan="2">Characteristic</th><th rowspan="2">m/e</th><th rowspan="2">Section</th><th>Type release</th><th>Capability</th><th>Inspection</th></tr>
<tr><th>Machine manufacturer</th><th>Machine manufacturer & cable manufacturer</th><th>Cable manufacturer</th></tr>
<tr><td colspan="7">Qualification tests</td></tr>
<tr><td colspan="2">Peeling force test</td><td>m</td><td colspan="4">Section 7.1.3</td></tr>
<tr><td colspan="2">Individual node variant</td><td>m</td><td>Section 8.1.1.2.2</td><td>—</td><td>—</td><td>—</td></tr>
<tr><td colspan="2">Typical individual node</td><td>m</td><td>Section 8.1.1.2.3</td><td>—</td><td>—</td><td>≥ 25</td></tr>
<tr><td colspan="2">Typical production node</td><td>m</td><td>Section 8.1.1.2.5</td><td>—</td><td>—</td><td>—</td></tr>
<tr><td colspan="2">Boundary samples for the typical individual node</td><td>m</td><td>Section 8.1.1.2.4</td><td>—</td><td>50 (r) each</td><td>—</td></tr>
<tr><td colspan="2">Smallest possible node cross section</td><td>m</td><td>Section 8.1.1.3.1</td><td>50 (r)</td><td>—</td><td>—</td></tr>
<tr><td colspan="2">Medium node cross section</td><td>m</td><td>Section 8.1.1.3.2</td><td>50 (r)</td><td>—</td><td>—</td></tr>
<tr><td rowspan="2">Largest possible node cross section</td><td>Minimum number of conductors</td><td>m</td><td>Section 8.1.1.3.3</td><td>50 (r)</td><td>—</td><td>—</td></tr>
<tr><td>Maximum number of conductors</td><td>m</td><td>Section 8.1.1.3.4</td><td>50 (r)</td><td>—</td><td>—</td></tr>
<tr><td colspan="2">Tensile force test</td><td>m</td><td>Section 7.1.2</td><td>50 (r)</td><td>—</td><td>—</td></tr>
<tr><td colspan="2">Bend test</td><td>m</td><td>Section 7.1.4</td><td>1</td><td>—</td><td>—</td></tr>
<tr><td colspan="2">Environmental test</td><td>m</td><td>Section 7.2</td><td>—</td><td>—</td><td>—</td></tr>
<tr><td colspan="2">Degree of compression</td><td>e</td><td>Section 5.6.2</td><td>—</td><td>1</td><td>—</td></tr>
<tr><td colspan="7">Error detection</td></tr>
<tr><td colspan="2">Pressing and welding dimensions</td><td>e</td><td>Section 6.3.3</td><td>10</td><td>1</td><td>1</td></tr>
<tr><td colspan="2">Welding operation</td><td>e</td><td>Section 6.3.4</td><td>10</td><td>1</td><td>1</td></tr>
<tr><td colspan="7">Visual inspection</td></tr>
<tr><td colspan="2">General requirements</td><td>e</td><td>Section 6.5.1</td><td>100%</td><td>100%</td><td>100%</td></tr>
<tr><td colspan="2">Strands that are sticking out or have been squeezed out</td><td>e</td><td>Section 6.5.7</td><td>100%</td><td>100%</td><td>100%</td></tr>
<tr><td colspan="2">Flash</td><td>e</td><td>Section 6.5.6</td><td>100%</td><td>100%</td><td>100%</td></tr>
<tr><td colspan="2">Cable insulation fused on</td><td>e</td><td>Section 6.5.5.3</td><td>100%</td><td>100%</td><td>100%</td></tr>
<tr><td colspan="2">Cable insulation elements melting together</td><td>e</td><td>Section 6.5.5.4</td><td>100%</td><td>100%</td><td>100%</td></tr>
<tr><td colspan="7">Dimensions</td></tr>
<tr><td colspan="2">Measurable node height</td><td>m</td><td>Section 5.5.2.2</td><td>v</td><td>v</td><td>—</td></tr>
<tr><td colspan="2">Node length</td><td>e</td><td>Section 5.5.2.5</td><td>v</td><td>v</td><td>v</td></tr>
<tr><td colspan="2">Projection l_D</td><td>e</td><td>Section 5.5.2.5</td><td>v</td><td>v</td><td>v</td></tr>
<tr><td colspan="2">Insulation distance $l_{a, ALi}$</td><td>e</td><td>Section 5.5.2.5</td><td>v</td><td>v</td><td>v</td></tr>
<tr><td colspan="7">Documentation</td></tr>
<tr><td colspan="2">Photographic documentation</td><td>—</td><td>—</td><td>2 (v, w)</td><td>—</td><td>—</td></tr>
</table>

Table 5 (continued)

Characteristic	m/e	Section	Type release	Capability	Inspection
			Machine manufacturer	Machine manufacturer & cable manufacturer	Cable manufacturer
e Evaluate m Measure r Including capability verification v First and last nodes of the welding batch w je An image of the weld node's sonotrode side and an image of the weld node's anvil side					
The numbers in the columns indicate the number of test samples.					

Table 6 – Qualification matrix for the production release of weld nodes

Characteristic	m/e	Section	Production Pre-assembly	Production at the assembly line (e.g., KSK)
			Cable manufacturer	Cable manufacturer
Qualification tests				
Peeling force test	m	Section 7.1.3		
Individual node variant	m	Section 8.1.1.2.2	—	—
Typical individual node	m	Section 8.1.1.2.3	2 (t)	—
Typical production node	m	Section 8.1.1.2.5	—	3 (u) each
Boundary samples for the typical individual node	m	Section 8.1.1.2.4	—	—
Smallest possible node cross section	m	Section 8.1.1.3.1	—	—
Medium node cross section	m	Section 8.1.1.3.2	—	—
Largest possible node cross section – Minimum number of conductors	m	Section 8.1.1.3.3	—	—
Largest possible node cross section – Maximum number of conductors	m	Section 8.1.1.3.4	—	—
Tensile force test	m	Section 7.1.2	—	—
Bend test	m	Section 7.1.4	—	—
Environmental test	m	Section 7.2	—	—
Degree of compression	e	Section 5.6.2	—	—
Error detection				
Pressing and welding dimensions	e	Section 6.3.3	—	—
Welding operation	e	Section 6.3.4	—	—
Visual inspection				
General requirements	e	Section 6.5.1	100%	100%
Strands that are sticking out or have been squeezed out	e	Section 6.5.7	100%	100%
Flash	e	Section 6.5.6	100%	100%

Table 6 (continued)

Characteristic	m/e	Section	Production Pre-assembly	Production at the assembly line (e.g., KSK)
			Cable manufacturer	Cable manufacturer
Cable insulation fused on	e	Section 6.5.5.3	100% a)	100% a)
Cable insulation elements melting together	e	Section 6.5.5.4	100% a)	100% a)
Dimensions				
Measurable node height	m	Section 5.5.2.2	—	—
Node length	e	Section 5.5.2.5	2 b)	2 b)
Projection l_D	e	Section 5.5.2.5	2 b)	2 b)
Insulation distance $l_{a, ALi}$	e	Section 5.5.2.5	2 b)	2 b)
Documentation				
Photographic documentation	—	—	—	—
m Measure e Evaluate t Per batch u Daily; always the same node combination				
The numbers in the columns indicate the number of test samples.				
a) Only for node cross sections A_K > 30 mm²; otherwise, random samples as per cable manufacturer specification. b) The typical individual and production nodes are evaluated accordingly before the peeling force tests.				

Table 7 – Qualification matrix for weld nodes

Characteristic		m/e	Section	Standard node			Special node		
				Initial release	Calibrating known nodes	Parameter change	Initial release	Calibrating known nodes	Parameter change
				Cable manufacturer			Cable manufacturer + part owner		
Qualification tests									
Peeling force test		m	Section 7.1.3						
Individual node variant		m	Section 8.1.1.2.2	50 (r)	3	3	50 (r)	3	3
Typical individual node		m	Section 8.1.1.2.3	50 (r)	3	3	50 (r)	3	3
Typical production node		m	Section 8.1.1.2.5	50 (r)	3	3	50 (r)	3	3
Boundary samples for the typical individual node		m	Section 8.1.1.2.4	—			—		
Smallest possible node cross section		m	Section 8.1.1.3.1	—			—		
Medium node cross section		m	Section 8.1.1.3.2	—			—		
Largest possible node cross section	Minimum number of conductors	m	Section 8.1.1.3.3	—			—		
	Maximum number of conductors	m	Section 8.1.1.3.4	—			—		

Table 7 (continued)

Tensile force test	m	Section 7.1.2	—	—
Bend test	m	Section 7.1.4	—	1
Environmental test	m	Section 7.2	—	—
Degree of compression	e	Section 5.6.2	—	—
Error detection				
Pressing and welding dimensions	e	Section 6.3.3	—	10
Welding operation	e	Section 6.3.4	—	10
Visual inspection				
General requirements	e	Section 6.5.1	100%	100%
Strands that are sticking out or have been squeezed out	e	Section 6.5.7	100%	100%
Flash	e	Section 6.5.6	100%	100%
Cable insulation fused on	e	Section 6.5.5.3	100%	100%
Cable insulation elements melting together	e	Section 6.5.5.4	100%	100%
Dimensions				
Measurable node height	m	Section 5.5.2.2	v	v
Node length	e	Section 5.5.2.5	v	v
Projection l_D	e	Section 5.5.2.5	v	v
Insulation distance $l_{a, ALi}$	e	Section 5.5.2.5	v	v
Documentation				
Photographic documentation	—	—	—	—
m Measure e Evaluate r Including capability verification v First and last nodes of the welding batch				
The numbers in the columns indicate the number of test samples.				

Table 8 – Qualification matrix for cable release

Characteristics	m/e	Section	BMG/production release	Process verification
			BTV	Cable manufacturer
Qualification tests				
Peeling force test	m	Section 7.1.3	300 (r)	5
Individual node variant	m	Section 8.1.1.2.2	—	—
Typical individual node	m	Section 8.1.1.2.3	—	—
Typical production node	m	Section 8.1.1.2.5	—	—
Boundary samples for the typical individual node	m	Section 8.1.1.2.4	—	—
Smallest possible node cross section	m	Section 8.1.1.3.1	—	—
Medium node cross section	m	Section 8.1.1.3.2	—	—

Table 8 (continued)

Characteristics		**m/e**	**Section**	**BMG/production release**	**Process verification**
				BTV	**Cable manufacturer**
Largest possible node cross section	Minimum number of conductors	m	Section 8.1.1.3.3	—	—
	Maximum number of conductors	m	Section 8.1.1.3.4	—	—
Tensile force test		m	Section 7.1.2	50 (r)	—
Bend test		m	Section 7.1.4	25	—
Environmental test		m	Section 7.2	10	—
Peeling force test after environment test		e	Section 7.1.3	25	—
Error detection					
Pressing and welding dimensions		e	Section 6.3.3	—	—
Welding operation		e	Section 6.3.4	—	—
Visual inspection					
General requirements		e	Section 6.5.1	100%	100%
Strands that are sticking out or have been squeezed out		e	Section 6.5.7	100%	100%
Flash		e	Section 6.5.6	100%	100%
Cable insulation fused on		e	Section 6.5.5.3	100%	100%
Cable insulation elements melting together		e	Section 6.5.5.4	100%	100%
Dimensions					
Measurable node height		m	Section 5.5.2.2	v	v
Node length		e	Section 5.5.2.5	v	v
Projection l_D		e	Section 5.5.2.5	v	v
Insulation distance $l_{a, ALi}$		e	Section 5.5.2.5	v	v
Documentation					
Photographic documentation		—	—	2 (v, w)	—
e Evaluate m Measure r Including capability verification v First and last nodes of the welding batch w je An image of the weld node's sonotrode side and an image of the weld node's anvil side					
The numbers in the columns indicate the number of test samples.					

Table 9 – Specifications for wiring harness design

Characteristic	**m/e**	**Section**	**Drawing check**[a)]
			Cable manufacturer + part owner
Number of cables	e	Section 6.4.3	x
Individual cable combinations and cross sections	e	Section 6.4.4	x
Node size	e	Section 6.5.5	x

Table 9 (continued)

Characteristic	m/e	Section	Drawing check[a)]
			Cable manufacturer + part owner
Strands that are sticking out or have been squeezed out	e	Section 6.5.7	x
Position of weld node in the wiring harness	e	Section 6.6	x
Weld node insulation	e	Section 6.6.5	x
Mechanical protection for weld nodes	e	Section 6.6.6	x
m Measure e Evaluate x Risk analysis			
a) Design review and for submission of quotation			

9 Applicable documents

The following documents cited are necessary to the application of this document:

Some of the cited documents are translations from the German original. The translations of German terms in such documents may differ from those used in this standard, resulting in terminological inconsistency.

Standards whose titles are given in German may be available only in German. Editions in other languages may be available from the institution issuing the standard.

VW 60306-1 Electrical Cables in Motor Vehicles; Part 1: Copper Cable; Single-Core, Unshielded

VW 60306-4 Elektrische Leitungen für Kraftfahrzeuge - Leitungen aus Kupferlegierung; einadrig, ungeschirmt

VW 60330 Crimp Connections; Solderless Electrical Connections

VW 60360-1 Protection Systems for Wiring Harnesses in Motor Vehicles Adhesive Tapes; Test Guideline

VW 60360-3 Protection Systems for Wiring Harnesses in Motor Vehicles; Test Requirements for Sleeves, Hoses, and Tubing

DIN EN 60512-16-4 Connectors for electronic equipment - Tests and measurements - Part 16-4: Mechanical tests on contacts and terminations - Test 16d: Tensile strength (crimped connections)

DIN EN 60512-2-1 Connectors for electronic equipment - Tests and measurements - Part 2-1: Electrical continuity and contact resistance tests; Test 2a: Contact resistance; Millivolt level method

DIN EN ISO 6270-2 Paints and varnishes - Determination of resistance to humidity - Part 2: Condensation (in-cabinet exposure with heated water reservoir)

Appendix A (informative) Additional explanations

A.1 General information

The explanations in section A.2 to section A.4 are intended to make this standard easier to understand and are provided for information purposes only. If these explanations contradict specifications, definitions, requirements, or tests, the explanations must be disregarded in terms of those contradictions, i.e., specifications take precedence.

A.2 Cable insulation circumscribed circle

The circumscribed circle containing the cable insulation elements as per figure A.1 must have the same size as much as possible in both branch-off directions, particularly in the case of connecting nodes that need to be sealed (see section 6.4.3 and section 6.6.5.3). The cables are distributed accordingly on both sides.

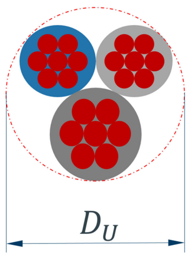


Figure A.1 – Circumscribed circle for the cable insulation elements with diameter D_U

A.3 Compression

The gaps between the individual wires must not be connected to each other.

A.4 Height-width ratio

The height-width ratio is a node dimension that has been found to be advantageous in real life. An exact value cannot be specified for the height-width ratio when taking into account the manufacturing tolerances for the node height and width and the welding dimension as a check size. The dispersion range shown in figure 18 is taken into account for the aforementioned influences.