TRAFOFLUID

HANDBOOK

OF RESISTANCE WELDING

RESISTANCE-WELDING TECHNIQUES

Electric resistance welding includes a group of autogenous pressure procedures in which the heat necessary to create the weld is produced on the basis of the Joule effect by the flow of a high arises from the Joule effect, produced by the passage of an intense current through the two elements to be connected and the welding point,with no filler materials. .

No filler materials are used.

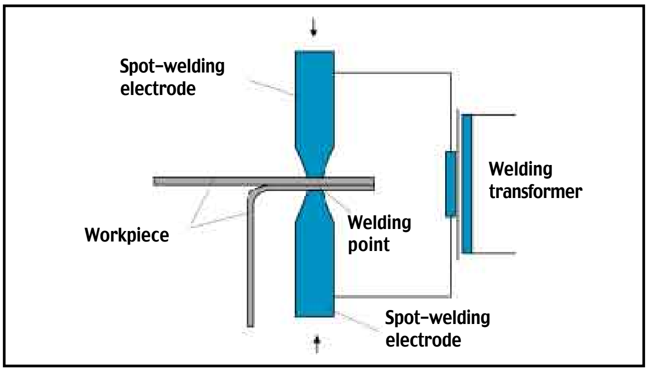
The various resistance-welding procedurestechniques are distinguished characterized by the a different shape of the stitches and a different the welding techniqueprocedure.

They can be classified as follows:

1. Lap welding
   1.1. spot welding
   1.2. projection welding
   1.3. roll welding
2. Butt welding
   2.1. forge welding
   2.2. flash welding

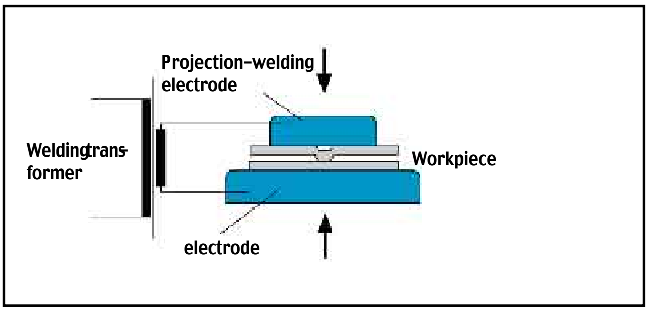
1. LAP WELDING

1.1. SPOT WELDING

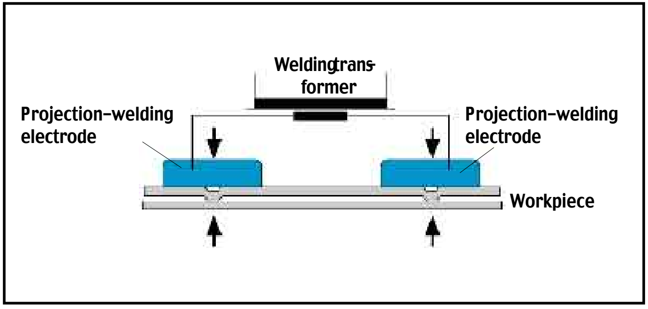


High gripping pressure, extremely short welding time and very intense welding current are the distinctive features of this technique. The shape of the electrodes determines the concentration of current distribution.

1.2. PROJECTION WELDING

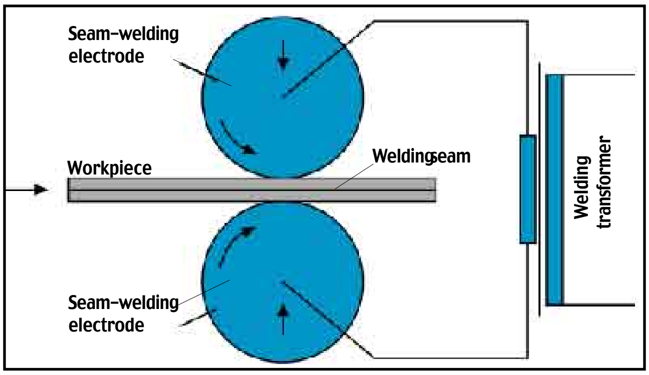


This is a method of resistance welding for simultaneous and single or multiple stitches used in certain types of work done serially on small parts. The concentration of the current on the welding spot is determined by the projection, prepared by drawing a single metal sheet .



1.3. ROLL WELDING

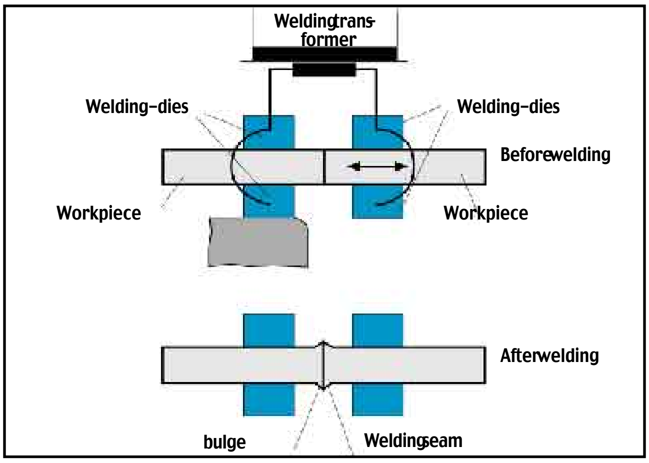
This is a method of resistance welding on overlapping seams performed using two roll-shaped electrodes. Compared to spot welding, roll welding requires more intense currents and stronger pressure to handle the same thickness.



2. BUTT WELDING

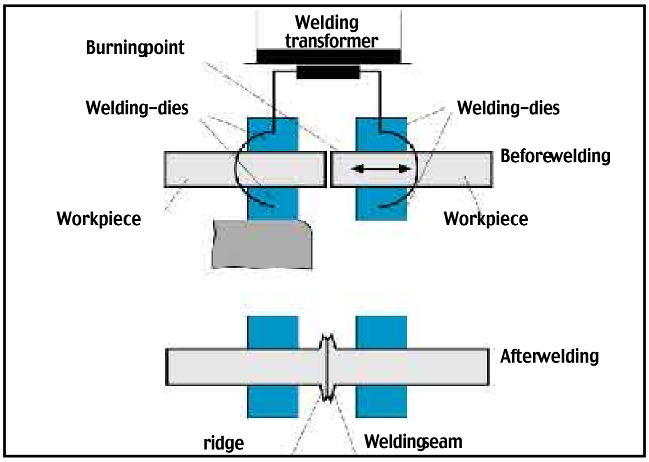
2.1. FORGE BUTT WELDING

The parts to be welded are gripped between welding dies. The ends of the two parts must be pressed against each other before the current can be passed through them. The preparation of the edges to be welded is important: they must be perfectly parallel and smooth and any rust must be removed. The parts must have the same shape and be made of the same material because otherwise, the heating will not be symmetrical .



2.2 FLASH BUTT WELDING

This is a more modern version of the previous method and it permits welding parts with different cross-sections or even made of different materials. It does not require the thorough preparation needed for the forge method. The voltage is applied through the ends of the two parts as they are drawn close together.



3. VOLTAGE AND CURRENT VALUES REQUIRED FOR RESISTANCE WELDING

The electrical current values required for welding vary in relation to many parameters, such as the thickness and type of metal to be welded, the diameter of the electrodes, the speed of the rolls, etc.
Nevertheless, the current values can range from 1.5 to 170 KA.
The secondary voltage of the transformer will vary according to the length and cross-section of the electrodes and the internal characteristics of the transformer.
Usually, the maximum voltage of the secondary does not exceed 26V, due to undesirable side effects that can cause flashing, etc.
The required voltage at the ends of the materials to be welded can go from values of a few tenths of a volt to a maximum of 3 V.
The difference between the no-load voltage of the transformer and the voltage required for welding is what overcomes the sum of the voltage drop of the transformer and of the welding circuit.

4. THE FUNCTION OF TRANSFORMERS IN RESISTANCE WELDING

As explained above, the welding processes we have examined require low voltage and very high current.
The purpose of the transformer is to change the voltage (V) and current (A) parameters of the electrical mains, leaving the product of the two values V x I constant, representing the apparent power.
On the primary side, we have a power of V x I, expressed in KVA, given by the product of the mains voltage value for a relatively low current.
On the secondary, the same power is obtained by the product of a low voltage for a very high current value.

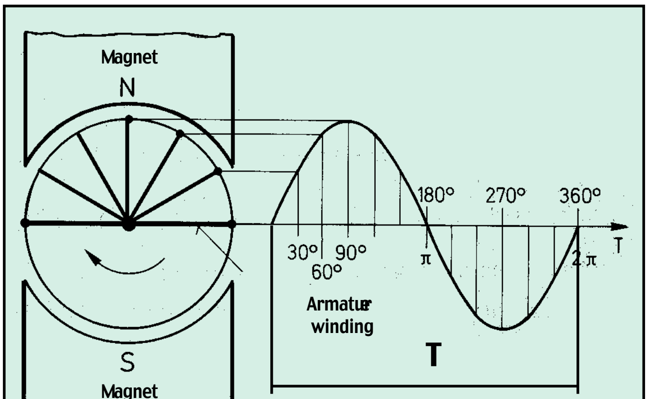
5. REGULATING THE WELDING CURRENT AND TIME

Thanks to modern electronics, it is now possible to find equipment on the market that will permit the programming of all parameters required for welding, such as current intensity, welding time and pause time.
Pause time is the sum of the times required to close and open the electrodes, shift the pliers and so on.
The welding time is usually expressed as the number of cycles or periods.
The cycle, understood as the period of an alternating magnitude (mains with AC voltage at 50 Hz), represents the constant time interval between two values with the same magnitude and sign.

$$T = \text{period} = \frac{1}{f}$$

For $f = 50$ Hz $T = \frac{1}{50} = 0.020$ seconds (20 milliseconds)

For $f = 1000$ Hz $T = \frac{1}{1000} = 0.001$ seconds (1millisecond)



formation of a sinus curve

6. TRANSFORMER BEHAVIOR DURING OPERATION

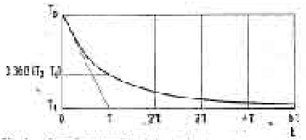
6.1. TRANSFORMER HEATING AND COOLING

During operation, the transformer heats up until it reaches its equilibrium temperature.
The temperature of the windings is proportional to the power they dissipate. In turn, the power that is lost varies with the square of the current.
The temperature, or rather the over-temperature, of the windings with respect to the coolant depends on a number of factors but with loss being equal, it depends mainly on the thermal resistance of the insulation placed in the windings.
The air hitting the transformer also helps dissipate the heat that is generated.
In water-cooled transformers, the cooling action of the air is negligible.
When the transformer stops working, all the components cool until they reach the temperature of the cooling water.
The temperature variation of the transformer in relation to time follows an exponential law.
The time it takes the transformer to reach its equilibrium temperature depends on the time constant **t.**

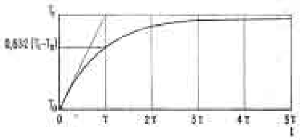
6.2. TIME CONSTANT t

6.2.1. Time constant t is a measurable physical magnitude (ISO 5826 standards, paragraph C 2).
6.2.2. It is a characteristic of the transformer.
6.2.3. It determines the heating and cooling speed of the transformer.
6.2.4. It varies in relation to transformer mass .
6.2.5. It is expressed in units of time (seconds).
6.2.6. It corresponds to the time it takes the transformer to reach 63% of the equilibrium over-temperature.

In effect, it can be said that the transformer reaches its equilibrium temperature with an approximation of over 1% after a period corresponding to five time constants. .



Exponent curve of temperature decrease
τ = time constant

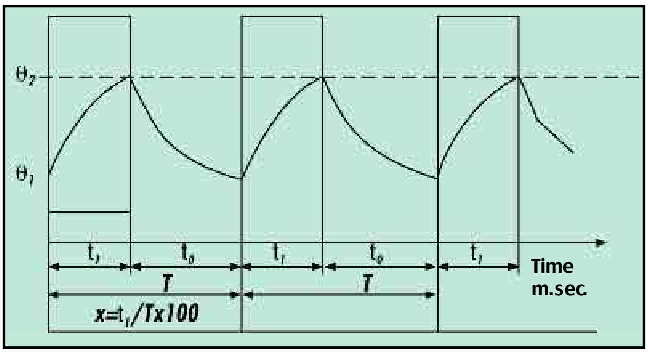


Exponent curve of temperature increase
τ = time constant

7. INTERMITTENT OPERATION

In general, the transformers used in the field of resistance welding never operate continuously but intermittently, with periods of operation and pauses .
During operation (welding), the transformer is supplied at its rated voltage and the welding currents flow through its windings .
During the pauses, the transformer is not powered.
This type of operation is defined as “intermittent”.
The characterization of intermittent duty is given by the duty cycle identified with the letter X (ISO 5826) and expressed as a percentage (on the specification tags of certain electrical machines the duty cycle is listed as ED%) .

The duty cycle corresponds to the percentage ratio between loading time (welding) (t_1) and cycle time (T), where T is the sum of the loading time (t_1) and the pause time (t_0).
The cycle time and the duty cycles can vary according to the welding cycle and the operating conditions of the transformer .



Over a welding cycle, the transformer heats up during the welding and cools off during the pause time. Its temperature varies between q1 and q2.

The graphic representation of this phenomenon is shown in the illustration below, although it indicates the temperature variations once the condition of thermal equilibrium has been reached.

8. HOW THE RATING PLATE SPECIFICATION DATA OF A TRANSFORMER VARIES ACCORDING TO THE DUTY CYCLE

The specifications on the nameplate, listed on every transformer, are established by the standards with which it was designed and manufactured. The information that is usually listed is:

- 8.1. Identification data (manufacturer, trademark, serial number, year, reference standards, etc.)
- 8.2. Electrical characteristics (U1=primary voltage, frequency in Hz, U_{2o} =no-load secondary voltage, P power in VA, I2 = secondary current, etc.)
- 8.3. Other characteristics (Q =flow rate in liters/minute, □p = pressure drop in bar, protection class, insulation class, weight, etc.)

The data that can differ usually involve the duty cycle values to which the power P and current I values refer.

According to ISO 5826 standards, the rduty cycle, to which the power (P_p) and current (I_p) values refer, is 100% and it corresponds to permanent duty.

The P and I data for the operating factorduty cycle = 50% are also allowed to be listed (the standards indicate that this option will undergo a transition period, but without defining its limits).

In the field of medium-frequency transformers, the data are commonly listed for an duty cycle of 20%.

The values are indicated with I_p and P_p if they refer to continuous duty or X =100%.

The values are indicated with $I_{2/50}$ P_{50} if they refer to a duty cycle of = 50%.

The values are indicated with $I_{2/20}$ P_{20} if they refer to duty cycle of =20%.

The formulas to be used to calculate the current and power values at duty cycles other than the ones listed on the specification tag are given below.

These simplified formulas are valid only when the ratio between the time constant and the longest welding cycle (T) is over five

$$P_x = P_p\sqrt{\frac{100}{X}} \qquad I_{2X} = I_{2p}\sqrt{\frac{100}{X}}$$

where:

- P_x e I_{2X} indicate the new P and I_2 values in relation to a new duty cycle other than 100%.
- X (under the root sign) = new duty cycle to which the P_x and I_{2X} will refer.

Example: Pp =80 KVA, to find the new P value in reference to an operating factorduty cycle of 5%.

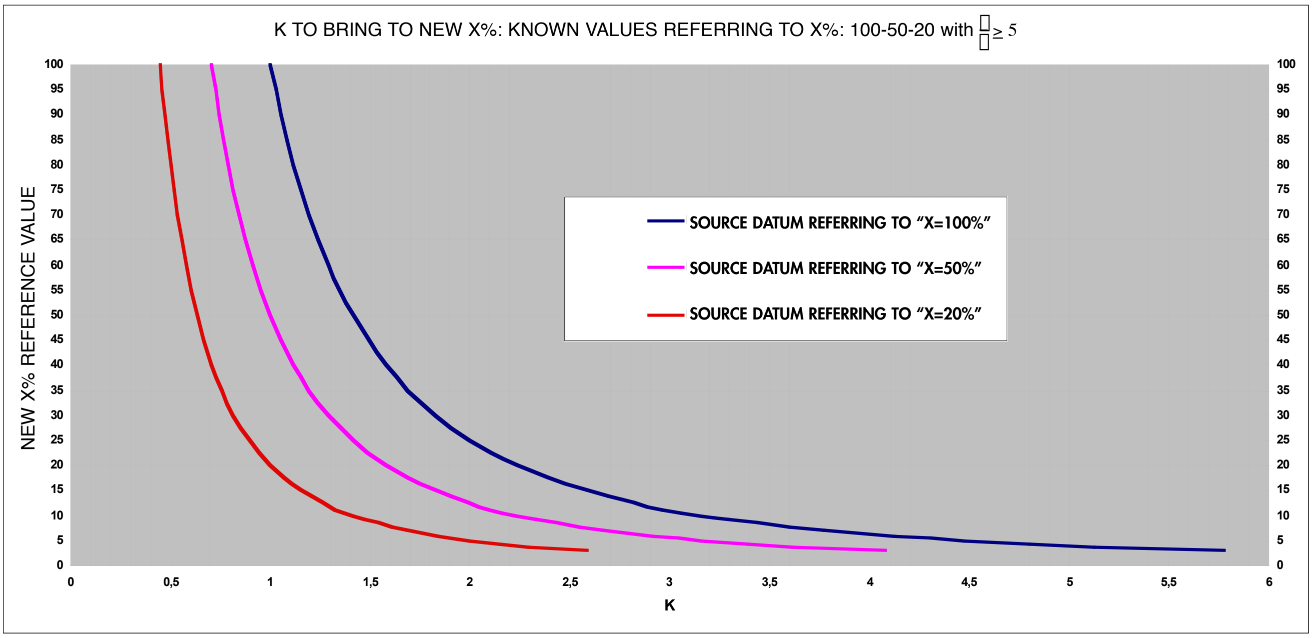
$$P_5 = 80\sqrt{\frac{100}{5}} = 357.7$$

To calculate the current, apply the same formula.

Use the same formula, inserting 100 as the numerator (under the root sign) and 2X as the denominator (instead of X), if the P and I values refer to 50%.

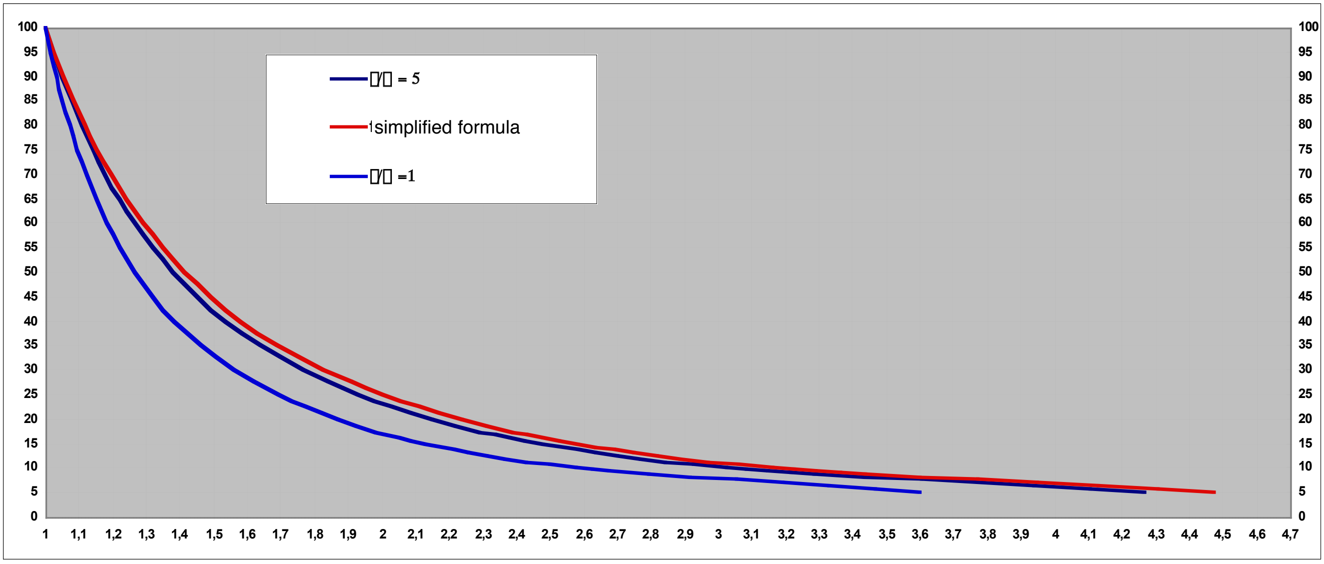
Use the same formula, inserting 100 as the numerator (under the root sign) and 5X as the denominator (instead of X), if the P and I values refer to 20%.

The following chart can be used to obtain the coefficient K for a quick calculation of the values of P and I in relation to the desired X% from the specification data referred to X%= 100-50-20.



The complete formulas listed in ISO 5826, attachment C, must be applied when the ratio between time constant t and cycle T is less than or equal to five.
The chart below lists the K coefficients by which the Pp and Ip values must be multiplied in order to obtain the new values referring to the new X%, in the two conditions in which the t/T ratio assumes the values of 5 and 1. For the purposes of comparison, the K values obtained using the simplified formula are shown.

K TO BRING TO NEW X% KNOWN VALUES REFERRING TO X=100%, WITH □/□=1 and 5



9. HOW TO OBTAIN THE EFFECTIVE R.M.S. VALUE OF THE CURRENT AND RATED CAPACITYPOWER RATING OF A TRANSFORMER IN THE PRESENCE OF A COMPLEX WELDING CYCLE

Let'us assume that a repetitive welding cycle must be performed, composed of three welding stitches and working with the following characteristics:

- U2 of the transformer =12.75 V
- The Ttime constant t of the transformer =200 seconds
- Overall cycle duration 2500 periods (2500*0.02 =50 seconds)
- First welding composed of three welding stitches, duration =50 periods, I_2=20 KA.
- Second welding composed of two welding stitches, duration =150 periods, I_2=5 KA.
- Third welding composed of five welding stitches, duration =70 periods, I_2=30 KA.

Determine the transformer power referred to X =100% and the value of I2 and P, effective duty cycle.

Solution:

$$I_{2p} = \sqrt{3 \square 20^2\,KA \square \frac{50}{2500} + 2^2 \square 5 \;\square \frac{150}{2500} + 5 \square 30^2 \square \frac{70}{2500}}$$

I_{2p} =11.225 KA
P_p =143.19 KVA

$$X = \frac{3 \square 50 + 2 \square 150 \square 5 \square 70}{2500} = 32\%$$

$I_{2/32}$ =19.84 KA
P_{32} =253 KVA

The values calculated with X =100% indicate that the windings can operate indifferently with 11.225 KA in permanent duty or with 19.84 KA with an duty cycle of 32%.
This means that the over-temperature of the windings in the two different conditions, after the initial transicut is identical.
An important parameter that will instead be different in the two above-mentioned conditions is the voltage available at the ends of the tips of the welder, because the voltage drops will differ.
In fact, the voltage drops are directly proportional to the current and are not affected by working time

It must also be noted that, as opposed to what takes place in the windings, in the iron core the two different duty cycles produce completely different temperatures.

10. BEHAVIOR OF THE IRON CORE DURING INTERMITTENT DUTY

The over-temperature that the iron core reaches does not depend on the intensity of the current that is supplied by the transformer, but by the operating induction of the magnetic iron.
Since the operating induction is proportional to the supply voltage of the transformer, the core losses are instantaneously always equal at the same supply voltage (and frequency).
The supply voltage and thus the losses in the iron, as opposed to the current and power losses in the windings, do not vary with the duty cycle.
The heating of the iron core nevertheless depends on the duty cycle and on its own time constant (the time constant of the iron, identified as t_m, is greater than the time constant t indicated in the specification data and referred to the windings).
The heating of the iron rises as the duty cycle increases.
The temperature reached by the core designed for intermittent duty could become hazardous for operator safety and harmful for the life of the transformer if used for permanent duty.
This is what prevents the use of the transformers for permanent-duty welding, even if the specification data may refer to an duty cycle of 100%.
In the event of operation in permanent duty, the transformer must have an iron core with a larger section compared to the transformers generally used in the field of resistance welding.

11. PARAMETERS CHARACTERIZING A TRANSFORMER

Two transformers with exactly the same specification data (primary voltage, secondary voltage, primary current, secondary current, frequency, etc.) can behave very differently during actual operation. This means that the two transformers merely seem to be the same.
The parameters that define if two transformers are the same are referred to as the "short-circuit parameters" . The short-circuit parameters are:

11.1. SHORT-CIRCUIT VOLTAGE = U_{cc} in V o U_{cc} %. if referring to top rated voltage.

11.2. SHORT-CIRCUIT IMPEDANCE = Z_{cc} = U_{cc}/I_p =vector sum of $\overline{R}_{cc} + \overline{X}_{cc}$

11.1. SHORT-CIRCUIT VOLTAGE

The main parameter that is used is short-circuit voltage, and in electrical machinery it is expressed as a percentage value referred to the rated voltage (primary or secondary).
The short-circuit voltage is the voltage required to make the winding's permanent rated current (I_p) circulate in it when it is closed in a short circuit.
The short-circuit voltage is thus expressed as the voltage necessary to overcome the internal impedance of the transformer when the permanent rated current passes through it.

11.1.1. The impedance is the vector sum of the two parameters of resistance Rcc and reactance Xcc .
11.1.2. The equivalent resistance (primary or secondary) depends on the cross-section of the conductors and on additional losses provoked by the scattered stray fields.
11.1.3. The equivalent reactance (primary or secondary), generally indicated with X (not to be mistaken for the duty cycle) is proportional to the supply frequency and it is influenced by the constructional and geometric parameters of the windings .

During the design phase, the engineers' objective is to achieve a U_{cc} % that is as low as possible, seeking a constructional compromise that is economically and dimensionally optimum in relation to the power of the transformer.
In the case of transformers designed to operate at a frequency of 1000 Hz, the leakage reactance has a value that is 20 times higher than the value it would have at 50 Hz.

This condition makes the transformer design particularly complicated with frequencies that are higher than the mains, entailing special design experience.
When comparing two transformers, the transformer with a lower U_{cc} % is best.

11.2. IMPEDANCE OF THE WELDING CIRCUIT

Another important element that is added to the equivalent Z of the transformer is the impedance of the welder arms.
The Z impedance of the arms is also obtained from the vector sum of their resistance and reactance.
The resistance of the arms depends on the material used – copper and/or brass – and on their length and cross-section.
Reactance varies with the area between the two arms. In effect, in order to limit this parameter the two arms should be as close to each other as possible.
The total impedance of the welding circuit, given by the vector sum of the impedances of the transformer and the welder arms, limits the short-circuit current of the welder.

11.3. TRANSFORMER SHORT-CIRCUIT CURRENT

This is the current obtained by supplying a winding at the rated voltage when the other one is closed in a short circuit.
Depending on the winding being supplied, there can be a primary or secondary short-circuit current.

The short-circuit current can be calculated using the following formula:

$$I_{cc} = \frac{U_n}{U_{cc\%}} \square I_p$$

Example: a transformer with a rated Ucc of 20%, closed in a short circuit and supplied with its rated voltage, will deliver a current of 5 times Ip. All the supply voltage will be used to overcome its internal impedance.

11.4. WELDER SHORT-CIRCUIT CURRENT

This is the current obtained by supplying the welder at the rated voltage, with its arms closed at nominal pressure and without any welding material placed between them.

$$welderIcc = \frac{Un}{transformerZcc + welderarmZ}$$

$$welderIcc = \frac{Un}{\sqrt{(R_{cc} + R_{arms})^2 + (X_{cc} + X_{arms})^2}}$$

The resistance of the welding circuit can be calculated when the cross-section and length of the arms are known values.
For the reactance, this can be calculated when the geometric arrangement of the arms is known.
On customer request, Trafofluid can calculate these parameters.

The short-circuit currents of the welders or welding equipment can be obtained experimentally by following the indications of ISO 669 standards.

11.5. WELDING CURRENT

This is the current that is obtained by placing the materials to be welded between the tips of the welders.
The maximum value of the welding current can be less than 10-20% of the value of the welder short-circuit current.
The welding current thus also depends on the characteristics and dimensions of the materials to be welded.

12. ELECTRODYNAMIC PHENOMENA IN TRANSFORMERS

Two parallel conductors repel each other if the currents go in opposite directions.
Two conductors attract each other if the currents go in the same direction.
The electrodynamic forces tend to shift the conductors in the direction corresponding to an increase in total flux linkage.
The increased flux, in the case of opposite currents, is obtained by drawing the conductors apart.
This is what happens in the transformer secondary.
In making the windings, due consideration must thus be given to the electrodynamic forces.
In the particular case of welding transformers, the electrodynamic forces are especially intense in the secondary winding due to the high currents involved.
The technique of casting the transformers in resin, together with special anchoring techniques, limits the effects of these forces that could otherwise cause serious damage to the transformer.

The current values that the transformer would theoretically be able to furnish with a low duty cycle can be very high.
These current values, which are not thermally damaging, could harm the transformer over time as a result of the forces that are generated.
Therefore, it is advisable to limit the currents to a maximum value of

nine times I_p. This value is also set by paragraph 12 of ISO 5826 standards for executing the dynamic tightness.
For transformers with incorporated welding handles, according to ISO 10656 the maximum value that must be withstood by the transformer is limited to five times I_p.

13.TEMPERATURE LIMITERS

At the client's request, temperature limiters with NC or NO contacts can be inserted in the windings.
The function of these limiters is to intervene, should the rated temperature be exceeded, by opening or closing an electrical contact that can command an alarm or disconnect the welder through auxiliary circuits.
The response time of the limiter is affected by the mass of the transformer and thus the protection does not intervene instantaneously, but with a time constant that is higher than the one of the windings in which it is inserted.
The typical function of the limiter is to detect extended overloads, faults in the cooling circuit or a lack of water.
The limiter is not suitable for short phenomena because it does not intervene.
The rated temperatures of the limiters are 140 C for primary coils and 80 C for the secondary winding, with a tolerance of 5 C.
The technical features of the limiters used by Trafofluid are listed below:

13.1. Operating voltage 250V
13.2. Rated AC current with cos j = 1 = 10 A, with
cos j = 0.6 = 6.3 A
13.3. Duration of 10,000 operating cycles at rated current
13.4. Duration of 2,000 cycles at a current of 25 A
13.5. Isolation voltage 2.5 KV.

On request, thermocouples or different types of probes can be mounted to measure the temperature.
The wires of the thermostats are generally connected to terminals, either separately or serially. With some types of transformers, the temperature limiter inserted on the secondary can be made accessible and interchangeable.

14. MEASURING THE WELDING CURRENT

To measure the current delivered by the secondary during the welding process, paragraph 5.3 of ISO 10656 standards indicates the electrical characteristics of a generic "measuring device".
This device is a simple Rocowski coil composed of a toroidal winding around a cylindrical body.
The coil is connected exactly like a power transformer (stromwandler) and supplies a signal in mV that is proportional to the current passing through it.
Usually, the coil signal is sent to the electronic devices that control the welding, which regulate the current set by the operator, constantly comparing it to the values measured by the coil.
In the case of transformers with two secondaries, a coil can be mounted on each winding.
For the serial connection of the two coils, the polarity of each signal must be checked and taken into consideration.
The output cables of the coils are connected to terminals set on the primary side of the transformer or in the position

15. INSTRUCTIONS FOR PROPER USE OF THE TRANSFORMERS

All the specification data of the transformer must be observed during use.
To obtain the current or power in reference to duty cycles other than the ones listed on the nameplate, follow the instructions listed above.
Use forklift trucks to handle the transformers.
To hoist them, insert four eyebolts in the specific threaded holes and use steel cables with a capacity higher than the weight listed on the nameplate.
Do not hook the hoisting cables to the projecting parts of the secondary!
Observe the maximum current values indicated in point 15 or in the reference standards.

15.1.PROTECTING OPERATORS AND TRANSFORMERS FROM RISKS

The transformers are tested individually with regard to the voltage withstand insulation test, as required by the reference standards (ISO 5826 - EN 50063 – NF EN 50063 – VDE 0545 part 1). However, the indications of EN 50063 standards must be applied, specifically with reference to the following provisions:
15.1.1. Protection against direct contac in normal duty conditions: paragraph 5.1.3 concerning water fittings, the characteristics of insulating hoses, the resistivity of the coolant.
15.1.2. Protection against indirect contact in cause of malfunction: paragraph 5.1.4 concerning the use of transformers in protection class II or the observance of one of the indications listed in paragraphs 5.1.4.1 through 5.1.4.7.

The above-mentioned paragraphs indicate different methods for connecting the secondary winding to the earthing cable either directly or through impedances, saturable inductors, etc.

15.2.TRANSFORMER INSTALLATION

15.2.1. Water characteristic

The water used for the cooling circuit has to have the following characteristics:
PH = from 7 to 9
Chloride: max. 20mg/l
Nitrates: max. 10mg/l
Sulfates: max. 100mg/l
Maximum hardness: 10 german degrees – 12,5 english degrees – 18 french degrees (1 french degree = 1gr CaCO3 every 100 l water).
The water resistivity has to be ≥ 20 ohm per meter (paragraph 5.1.3.1 – EN 50 063 standard) which corresponds to a conductivity of di 500 MS/cm (note: 1 Siemens = 1 Ohm^{-1})

15.2.2. Hydraulic circuit

Verify that the water flow rate reaches the value indicated on the nameplate, which normally varies from four to eight liters/minute, depending on the power of the transformer.
In certain special machines, the flow rate may be higher.
Water flow rates higher than the ones listed on the nameplate will improve transformer cooling but will also increase the pressure drop.
The temperature of the cooling water at the entry to the transformer must not exceed 30 C.
At the exit from the transformer, the water temperature can increase by about 10-15 C.
Special attention must be paid to the hardness of the cooling water (see characteristics at point 15.2.1) because during operation, lime deposits can reduce the cross-section of the pipe, thereby increasing the pressure drop. In this case, the head available to the circuit could be inadequate for guaranteeing the minimum required flow rate.
Lime deposits in the cooling circuit will also reduce the transmission of heat from the copper to the water, thus increasing the temperature of the tranformer.
When the water is particularly hard, we recommend installing a special water softener.
To keep water consumption down, it is best to provide for cooling the water in a closed circuit.
It is also advisable to install a flowmeter connected serially with the hydraulic circuit in order to trigger an alarm or disconnect the welder if there is no water.
If the cooling circuit supplies several transformers in parallel, in addition to installing a flowmeter at the entry to each transformer, it is also essential to ensure

uniform water distribution.

15.2.3. Electrical connection of the secondary to the welding circuit

During the finishing phase, the contact surfaces of the secondaries are machined to ensure good planarity and minimal roughness.
The surfaces of the conductors or of the welder arms that are placed in contact with the surfaces of the secondary must have the same degree of finishing.
If there is poor contact, the flow of the high electrical currents required for welding could cause sparking, corrosion and localized heating, leading to transformer malfunction.
The fastening bolts must be screwed on with a dynamometric wrench in order to guarantee the proper tightening torque.
Excessive tightening torque could break the copper wires, even if they are protected with special steel inserts.
To prevent the mechanical tightening tension, tension caused by heat expansion, electrodynamic strain or vibrations from being transmitted to the tranformer, it is advisable to insert a flexible conductor (stromband) between the secondary and the welder arms.

15.2.4. Connection of the transformer to the power mains

The cross-section of the transformer power mains, like the cross-section of connection cables to the command equipment, must be chosen considering the following two parameters:

15.2.4.1. Voltage drop.
This depends on the impedance of the mains, which varies according to the cross-section of the cables and their length, as well as the constructional features of the cable.
The drop is proportional to the current.
DV = ZI.
To calculate this drop, take the maximum current expected during use, independently of the duration.

15.2.4.2. Heating within the limits permitted by the type of insulation selected (VDE 0100 standards).
In choosing the cross-section of the cable, it is important to consider the maximum effective current, calculated by applying the formula indicated in point 12 above.
The cross-section of the cables must necessarily satisfy the more heavy-duty condition of the two that are indicated.
To select the automatic switches, verify that the currents and the durations do not trigger the cutout of the magnetic protection devices.

15.2.5. Calculating maximum welding current and/or power

Maximum welding power is obtained by multiplying the no-load secondary voltage of the transformer by the maximum welding current that, in turn, is obtained by applying the indications of points 14.1 – 14.2 – 14.3.
Trafofluid can perform the theoretical calculations required to obtain the short-circuit current of the welder.

16. TRANSFORMER MAINTENANCE

16.1. MAINTENANCE OF THE ELECTRICAL CIRCUIT

The electrical part does not normally require maintenance. However, we recommend periodic inspections of the connections of the secondary circuit in order to verify that there are no conducting dust deposits, marks of localized heating or microfusions caused by bad contacts.
If these problems are noted during these inspections, clean the contacts and, if necessary, repair them by machining the plates.

16.2. MAINTENANCE OF THE HYDRAULIC CIRCUIT

When working with very hard water without any softening conditioning, the hydraulic circuit of the transformer must be washed out periodically, using 1 liter hydrochloric acid on 100 liter water.
When mixing the acid with water and when washing the secondary with the acid, pay special attention to safety, protecting your eyes and unprotected parts of your body.
The frequency of this operation must be established based on experience, due to the variability of the factors involved in the encrustation process.