Application Note

«Welding diodes»

Contents

1. Welding diodes by JSC Proton-Electrotex

Cooperating with many welding equipment manufacturers, JSC Proton-Electrotex gained priceless experience in manufacturing welding diodes which have optimal reliability features and excellent electric parameters. In this Application note we cover general questions which will help you design effective and reliable welding rectifiers having low price and high quality. Below you can find specific features of our welding diodes, which must be taking into consideration during operation of devices.

You can find a full range of our welding diodes on our website via the link:

http://www.proton-electrotex.com/ru/product/diodes

Because welding equipment has rather low operation voltage going through the diode, to provide high voltage and more sufficient current density, thin semiconductor elements have been designed. Such thinness of welding diode housing enables low thermal resistance $\mathbf{R_{th}}$**.**

Welding diodes use semiconductor elements manufactured through alloy technology.

At present JSC Proton-Electrotex offers 4 types of welding diodes in ceramic housing and housingless design.

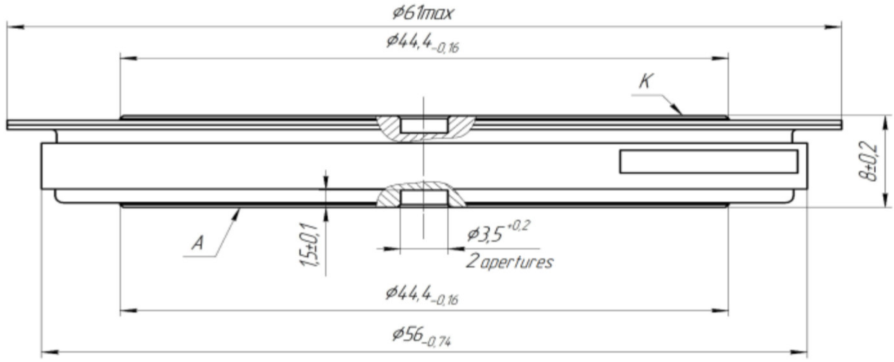

Figure 1. Dimensions of D053-7100 welding diode in ceramic housing.

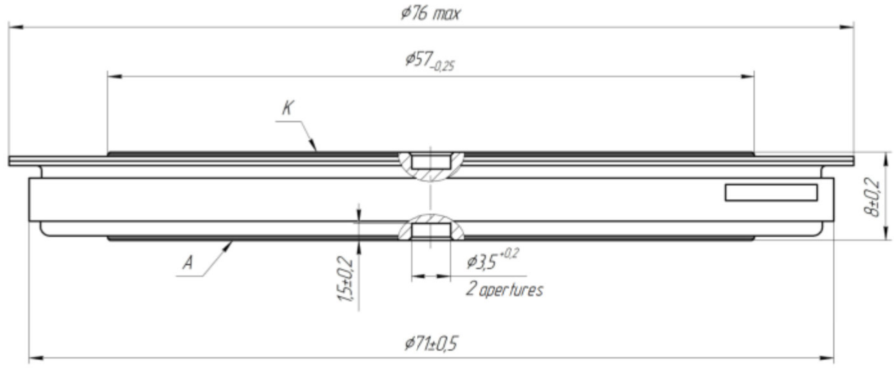

Figure 2. Dimensions of D063-11500 welding diode in ceramic housing.

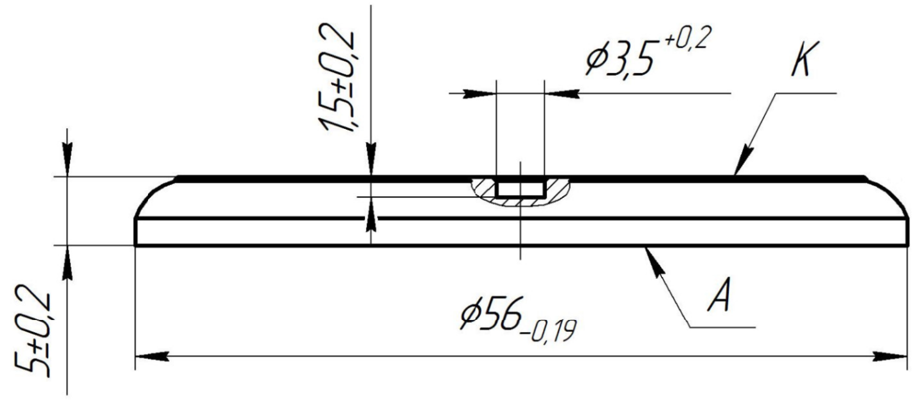

Figure 3. Dimensions of D056-9500 welding diode in housingless design

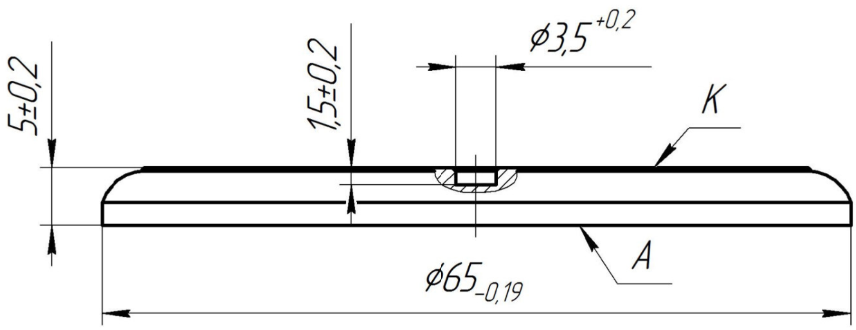

Figure 4. Dimensions of D066-12500 welding diode in housingless design.

Development of welding diodes in housingless design is conditioned by the necessity of weight and dimensions reduction for applications in welding and robotic equipment, for example.

To improve thermal performance, welding diodes are constructed with the reduced number of thermal contacts. These diodes have a silicon chip pressed by a copper electrode on the cathode side which serves as a mechanical buffer and the anode side is alloyed with molybdenum thermal compensator which is also the cover of the diodes. Although housingless welding diodes are more susceptible to environmental conditions, they have undeniable advantages – higher current density, lower weight and dimensions compared to the diodes in ceramic housing.

Standard welding diode may work at frequencies up to 7 kHz. However their optimal and most reliable frequency range is up to 2 kHz.

2. Datasheet user guide

The purpose of this section is to guide readers through welding diode datasheets and help them understand the datasheet contents. Welding diode parameters indicated in datasheets are defined. Data tables and diagrams of D056-9500-4 are used for explanation. However, this note is applicable for the whole range of welding diodes, both in ceramic housing and housingless design. The parameters are defined in correspondence with GOST 25529-82 (IEC 60747) standards.

Main advantages of a welding diode:

- High allowable load of direct current
- Low losses at reverse recovery
- High operating reliability

Main parameters:

Average forward current		I_{FAV}	9500 A
Repetitive peak reverse voltage		V_{RRM}	200 ÷ 400V
V_{RRM}, V	200	400	
Voltage code	2	4	
T_j, °C	– 60 ÷ 180		

Table 1. Main parameters of a welding diode.

I_{FAV} – average direct current. This is a maximum allowable value, which is measured at the set temperature of the device housing. Housing temperature must not exceed the maximum allowable value.

$$I_{FAV}=\sqrt{\left(\frac{V_{T0}}{5*r_T}\right)^2+\frac{T_{jmax}-T_C}{2,5*r_T*R_{thjc}}}-\frac{V_{(T0)}}{5*r_T}$$

V_{RRM} - repetitive peak reverse voltage. The highest immediate reverse voltage applied to a diode, including all repetitive transient voltages, but excluding all non-repetitive transient voltages.

T_j – datasheets have values **T_{jmin}** and **T_{jmax}** indicated in them. **T_{jmax}** is the temperature level, which is not to be exceeded in all operating conditions of the diodes. **T_{jmin}** – is the lowest allowable temperature level of diode operation and storage. This is conditioned by the fact that if the allowable temperature range is exceeded, electrical parameters of the diodes change. Difference in linear expansion index of construction materials may cause diode damage.

Conduction state parameters:

I_{FAV}	Average forward current	A	9500 9657 11814	T_c=110 °C; Double side cooled; T_c=100 °C; Double side cooled; 180° half-sine wave; 50 Hz	
I_{FRMS}	RMS forward current	A	14915	T_c=110 °C; Double side cooled; 180° half-sine wave; 50 Hz	
I_{FSM}	Surge forward current	kA	70.0 81.0	T_j=$T_{j\ max}$ T_j=25 °C	180° half-sine wave; 50 Hz (t_p=10 ms); single pulse; V_R=0 V;
			74.0 85.0	T_j=$T_{j\ max}$ T_j=25 °C	180° half-sine wave; 60 Hz (t_p=8.3 ms); single pulse; V_R=0 V;
I^2t	Safety factor	$A^2s \cdot 10^3$	24500 32805	T_j=$T_{j\ max}$ T_j=25 °C	180° half-sine wave; 50 Hz (t_p=10 ms); single pulse; V_R=0 V;
			22725 29980	T_j=$T_{j\ max}$ T_j=25 °C	180° half-sine wave; 60 Hz (t_p=8.3 ms); single pulse; V_R=0 V;

Table 2. Conduction state parameters.

I_{FRMS} – actual direct current in a period

I_{FSM} – maximum allowable single pulse peak of direct current of sinusoidal form and set duration.

This current is usually conditioned by short-circuit in the diode load circuit. It is implied that by the end of the pulse the protective device responds and the power circuit is deactivated.

Surge current pulse action must not lead to diode failure. Temperature at junction into surge current pulse period and during some time after that may considerably increase the value of maximum allowable junction temperature at long operation conditions of the diode.

Maximum allowable surge forward current rates at forward current pulse duration of 8.3 us and 10 us, and usually by the end of the current pulse reverse voltage is not applied to the diode.

Values are indicated for two pulse durations which correspond to circuit voltage frequency 50 and 60 Hz. Welding equipment has almost equal load and surge current values which are determined by transformer impedance in such a way that overload capacity rarely presents significant interest.

Direct current-voltage curve of the welding diode at 25°C and 180°C temperature is shown in Figure 5.

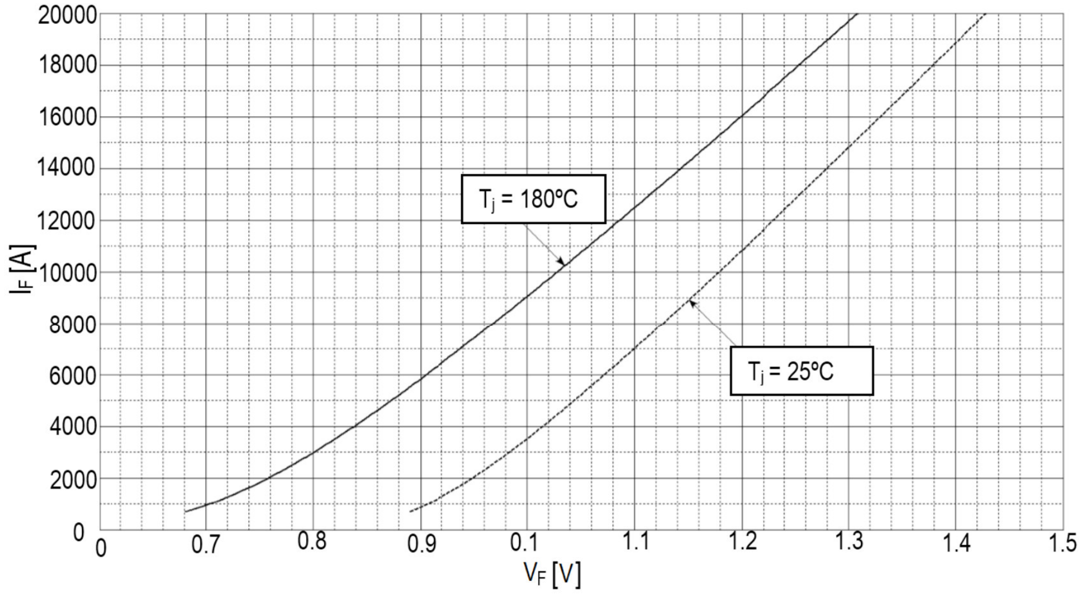

Figure 5. Current-voltage curve of D056-9500-4 welding diode

Direct current-voltage curve is characterized by the values shown in Table 3.

Conductive state characteristics:

V_{FM}	Peak forward voltage, max	V	1.08 0.98	T_j=25 °C; I_{FM} = 6300 A T_j=$T_{j\,max}$; I_{FM} = 8000 A
$V_{F(TO)}$	Forward threshold voltage, max	V	0.74	T_j=$T_{j\,max}$; 5000 A < I_T < 14000 A
r_T	Forward slope resistance, max	mΩ	0.030	

Table 3. Conductive state characteristics.

V_{FM} – peak forward voltage — maximum instant value of forward voltage at the indicated direct current. Measurements are performed at the room temperature or maximum allowable temperature.

$$V_{FM}=V_{(T0)}+\pi*r_T*I_{FAV} \quad .$$

Threshold voltage V_{T0} and slope resistance **r_T** are linear approximation of the direct current-voltage curve of the diode and are used to calculate device power losses **P_T**. For the indicated current, the losses can be calculated with the help of the equation below:

$$P_T=V_{T0}*I_{FAV}+r_T*I_{FRMS}^2 \quad ,$$

Where, **I_{FAV}** and **I_{FRMS}** are the parameters described above. To minimize the losses **V_{TO}** and **r_T** must have minimal values. It is necessary to note that linear approximation of on-state current-voltage characteristic is valid only within the set current limit. Beyond this limit the direct current-voltage characteristic is non-linear, which requires to use more complex models to describe the non-linear form of on-state current-voltage curve.

$V_{F(T0)}$ – threshold voltage. This is the value of the forward voltage determined by the intersection point of the current-voltage linear approximation with the voltage axis. In practice, threshold voltage of a welding diode is determined as the line crossing the current-voltage curve of the diode in two points, one of which corresponds to the instantaneous direct current value for the range indicated in the datasheets (for D056-9500-4 – 5000 A < IT < 14000 A).

r_T – on-state dynamic resistance. This is the resistance value determined by the slope of the linear approximation of the current-voltage line of the diode.

I_{RRM} – repetitive peak reverse current. This is the instantaneous value of the reverse current conditioned by repetitive pulse reverse voltage.

Thermal and mechanical parameters:

R_{thjc}	Thermal resistance, junction to case, max	°C/W	0.0050	Direct current	Double side cooled
R_{thjc-A}			0.0070		Anode side cooled
R_{thjc-K}			0.0150		Cathode side cooled
R_{thck}	Thermal resistance, case to heatsink, max		0.0035	Direct current	

w	Weight, typ	g	110	
D_s	Surface creepage distance	mm (inch)	2.0 (0.079)	
D_a	Air strike distance	mm (inch)	2.0 (0.079)	

Figure 4. Thermal and mechanical parameters

R_{thjc} – thermal resistance junction to case. This is the ratio of junction and case temperature margin to the power of the losses in the set operation regime of the diode.

To measure thermal resistance junction to case the diode is loaded with constant direct current. It is allowable to apply the alternating current with such frequency, which allows bypassing temperature variations of junction between the current pulses.

For diodes with one-side cooling thermal resistance junction to case is calculated by the below formula:

$$R_{th\,jcA}=\frac{(T_j-T_{cA})}{I_F U_F}$$ – diode cooling on the side of the anode

$$R_{th\,jcK}=\frac{(T_j-T_{cK})}{I_F U_F}$$ – diode cooling on the side of the cathode

For diodes with double-sided cooling thermal resistance junction to case is calculated by the below formulas:

$$R_{th\,jcA}=\frac{(T_j-T_{cA})}{T_{cA}-T_A}*R_{thcAa}$$

$$R_{th\,jcK}=\frac{(T_j-T_{cK})}{T_{cK}-T_a}*R_{thcKa}$$

$$R_{th\,jc}=\frac{R_{th\,jcA}*R_{th\,jcK}}{R_{th\,jcA}+R_{th\,jcK}}$$

R_{thck} – thermal resistance case to heatsink.

It is preferable to have **R_{thjc}** and **R_{thck}** as low as possible, because the silicon temperature determines the allowable current load of the diode. Moreover, temperature difference between junction and case conditions the load cycling capability and diode lifetime.

Z_{thjc} – junction thermal resistance.

$$Z_{thjc} = \frac{\left(T_{vi(0)} - T_{ref(0)}\right) - \left(T_{vi(t)} - T_{ref(t)}\right)}{\Delta P} \quad ,$$

Where **$T_{ref(0)}$, $T_{vi(0)}$** – set heatsink and environment temperature at the open circuit. **$T_{ref(t)}$, $T_{vi(t)}$** – heatsink and environment temperature at the time **t.** **ΔP –** change in diode power causing heatsink temperature increase.

Z_{thjc} – is the ratio of the junction and check point temperature margin in the end of the set period of time, causing the temperature change, to the intermittent change of the diode dissipated power in the beginning of this period of time. The dependence of **Z_{thjc}** on the duration of current **t** in case of the double-sided cooling, is shown in Figure 3. This function may be indicated as either a curve, or an analytical function with superposition for six exponential members. Analytical expression is applicable for computer calculations and enables simulation of the whole system.

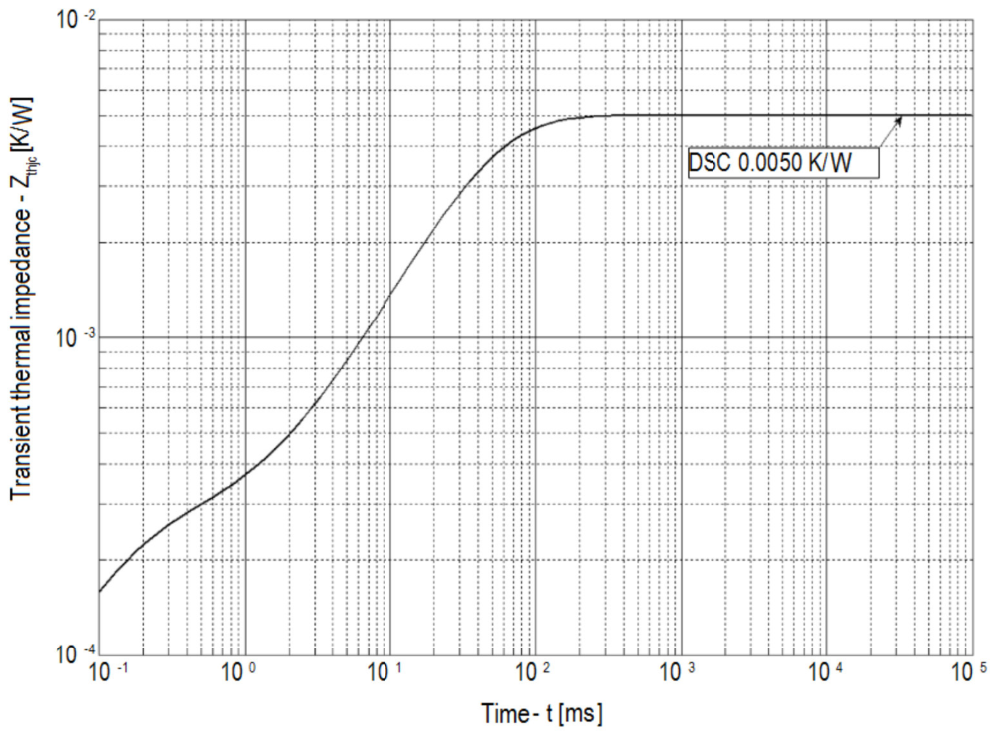

Figure 6. Curve for transient thermal impedance junction of diode D056-9500-4.

D_S – surface creepage distance — it is the shortest route along the housing and between the anode and cathode.

D_a – air strike distance — it is the shortest direct route between the anode and cathode in air.

Because of the fact that welding diodes are produced in the housings without ribs **$D_S = D_a$**.

Part numbering guide:

D	056	9500	4	N
1		2	3	4

1 – Design version;

2 – Average forward current;

3 – Voltage code;

4 – Climatic version according to GOST15150.

2.1 Power loss and maximum case temperature characteristics.

According to the standards for power semiconductors we present characteristics of forward power losses $\mathbf{P_T}$ for frequency 50 Hz. Figures 7 and 8 show forward power losses $\mathbf{P_{FAV}}$ as a function of the average forward current $\mathbf{I_{FAV}}$ for typical sine and square current wave form. The curves are calculated based on characteristics of the maximum forward voltage drop, $V_{FM(IF)}$, at T_{Jmax}, without considering any reverse recovery losses. The curves are valid only for 50-60 Hz operation.

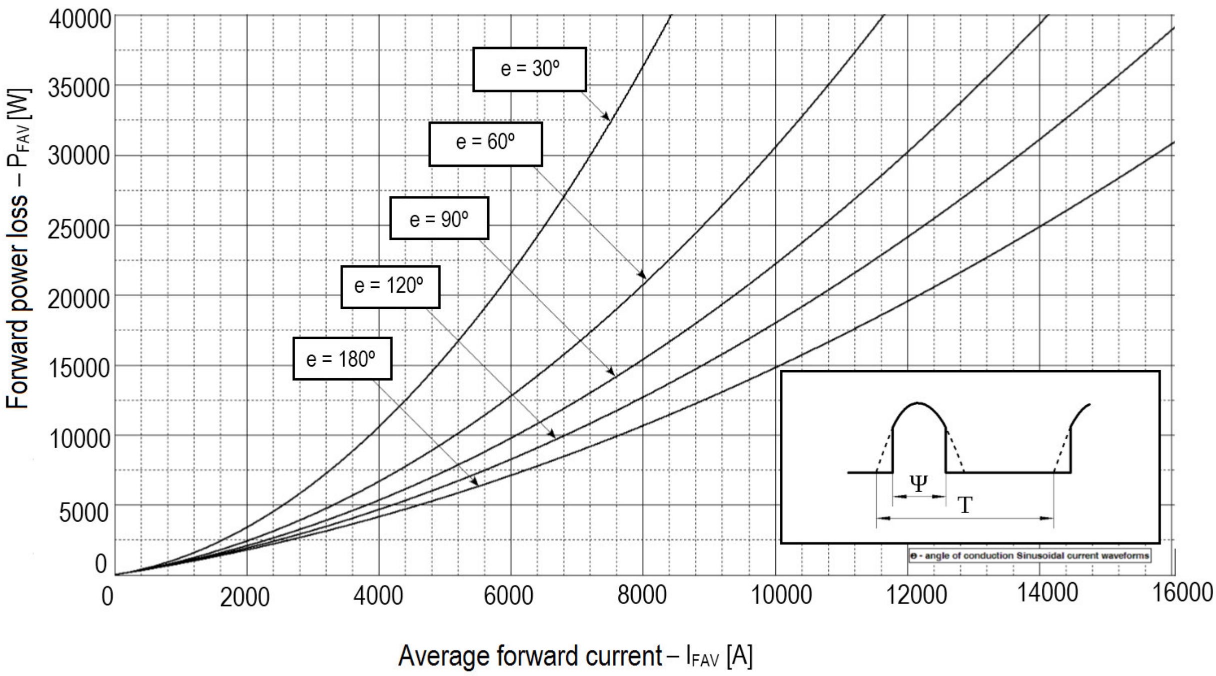

Figure 7. Forward power losses vs. average forward current, sine waveform with f=50 Hz.

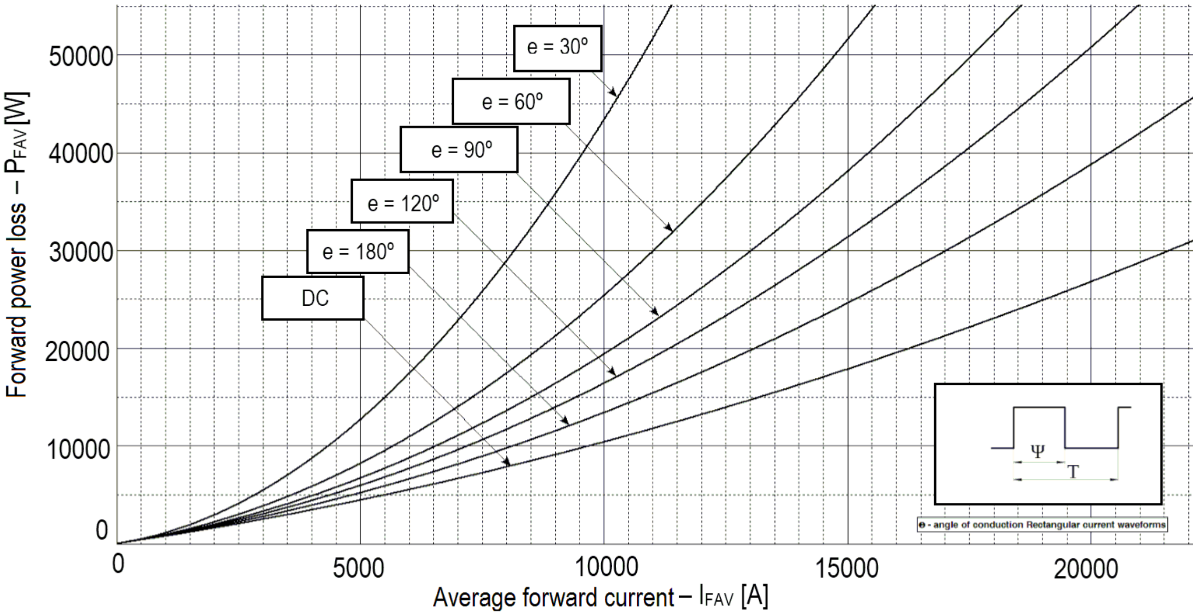

Figure 8. Forward power losses vs. average forward current, square waveform with f=50 Hz.

Figures 9 and 10 describe the maximal permissible case temperature **T_C** against the average forward current **I_{FAV}**, for typical sine and square current wave form (for inductive load). The curves are calculated based on the thermal resistance for the double side cooling, for the specified current waveforms and at the maximum junction temperature **T_{jmax}**.

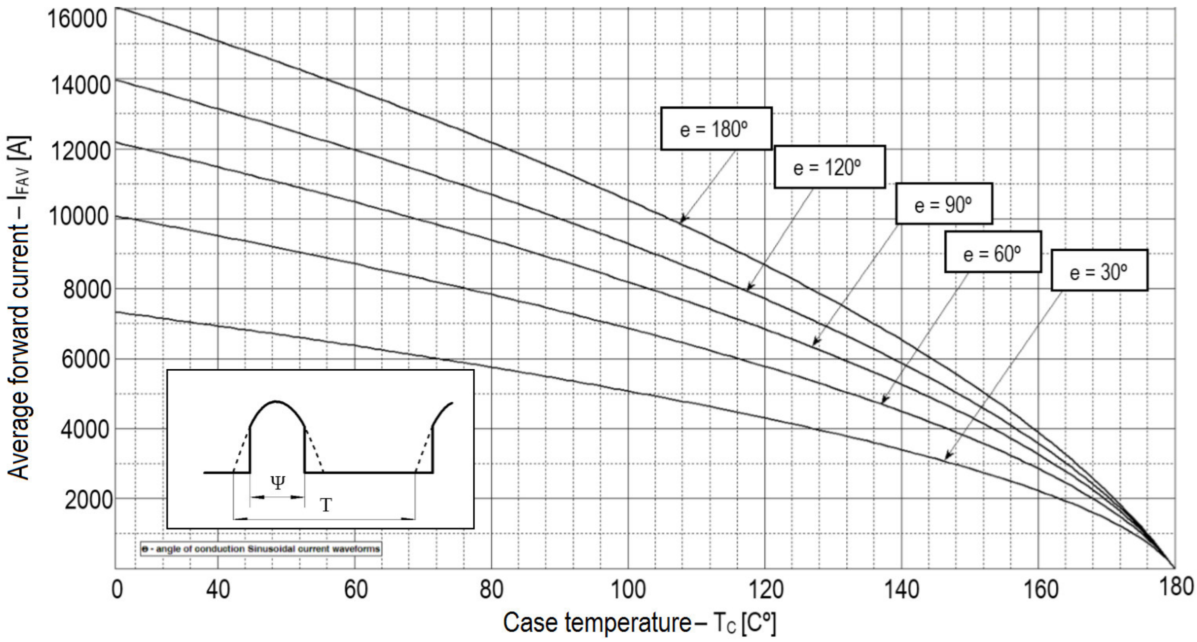

Figure 9. Maximum case temperature vs. average forward current, sine waveform with f=50 Hz.

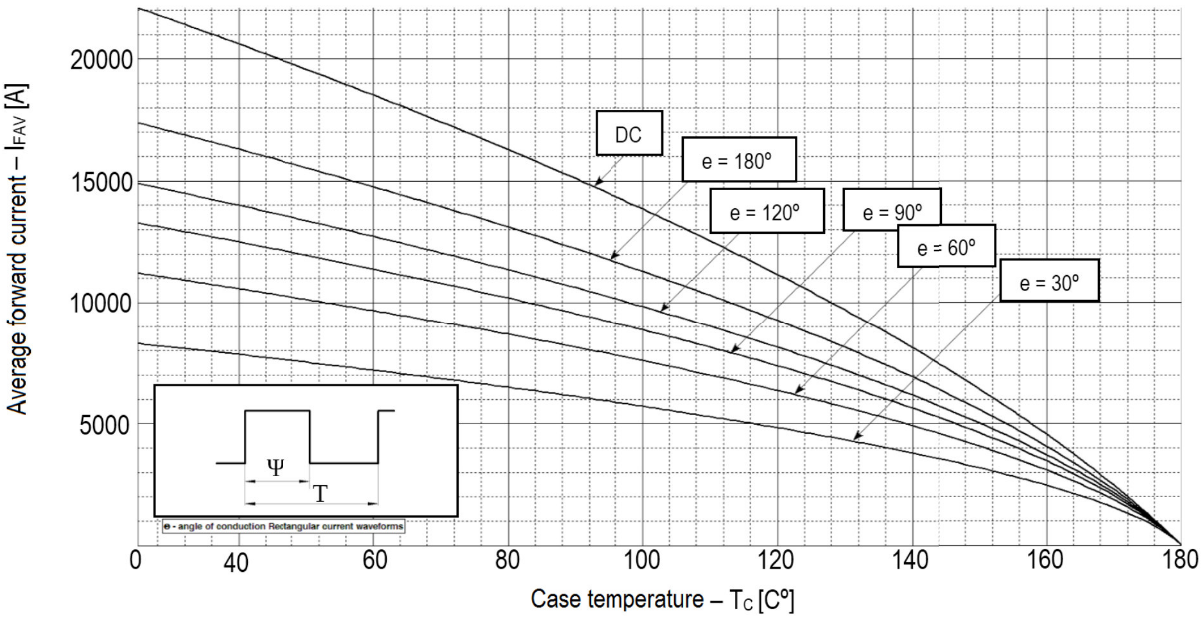

Figure 10. Maximum case temperature vs average forward current, square waveform with f=50 Hz.

2.2 Welding diodes turn-off characteristics.

In industrial machinery the welding diodes are used without any RC-circuits usually, it leads to excess voltage spikes generation at recovery process. Diodes produced by JSC Proton-Electrotex are designed to have a soft turn-off that does not generate voltage spikes in excess voltage class that allows their application without any protection.

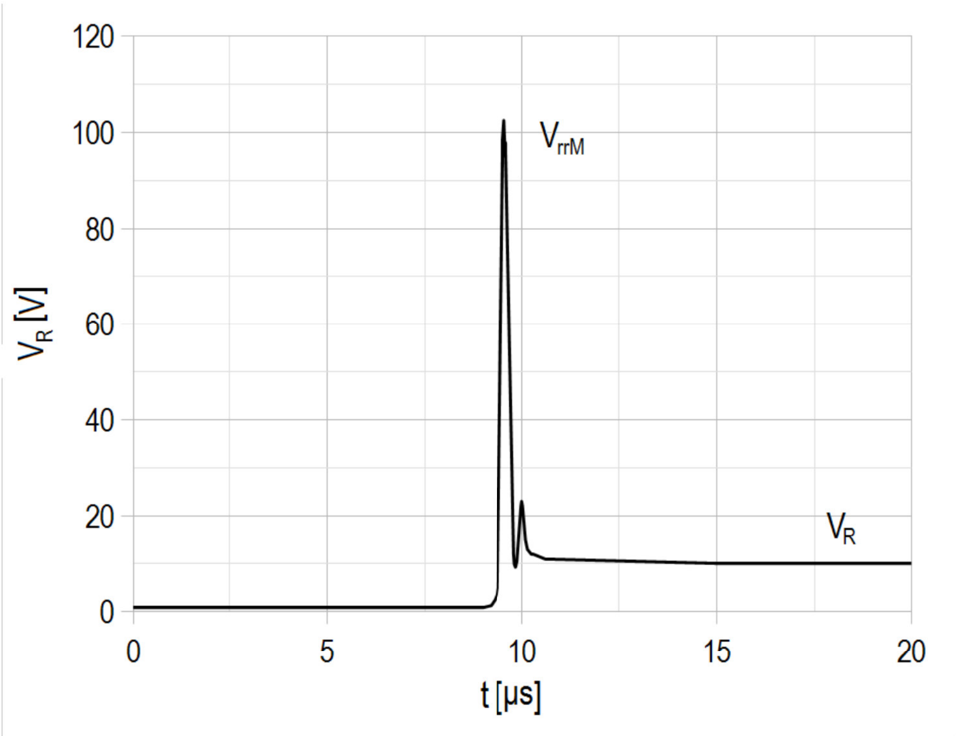

Figure 11. The typical turn-off wave form

3. Welding diode installation.

The mechanical design of the rectifier is crucial for its performance. An inhomogeneous press distribution is one of the most common reason of diode failure in welding application. Taking into account that the case thickness of the welding diode is not great, the press distribution during clamping with heat sinks should be considered as very significant.

3.1 Cooling.

Due to the need of high power density encountered in welding application, the water cooling is the only method used in practice. The cooling should be homogeneous over the whole diode contact surface. A single water channel through the center may not be sufficient for heavy-duty equipment and could lead to overheating of the diode external surface. Application of the cooling system with more complicated paths of water channels which would generate turbulence is advisable rather than using of simple straight paths.

3.2 Clamping and surface treatment.

In order to ensure qualified contact it is not worth using electroconductive paste if the following rules are observed:

- Contact surface of the heat sink must not have:
  - Roughness more than 1,6 µm;
  - Flatness deviation no more than 0,03 mm.
- Heat sinks must be galvanically plated by silver-nickel, pure silver, gold or nickel. Galvanic coating of the heat sink surface besides good thermal contact exclude electric erosion of the connectors.
- The mounting pressure must be homogeneously applied over the whole diode surface.

The mentioned above recommendations does though not exclude the use of a thin film of a light grease or oil, that ensures long chemical resistivity and decreases the influence of corrosion, however this interface grease must not make worse electrical contact.

4 Particularities.

4.1 Additional considerations regarding installation and application.

According to the fact that the housingless diodes do not have hermetically sealed housing, the special care must be taken during handling and operations of these diodes.

To minimize the environmental impact during transport and storage, the housigless diodes are delivered in a sealed foil. It is recommended to keep the diode in the foil and store it at the temperature specified in the datasheets for the diodes until the diodes are installed in the equipment.

The following advices should be considered for housingless diodes application:

- To protect the housingless diodes from environmental interaction it is recommended to use o-rings made of material resistant to high temperature and chemical aggression.
- The anode contact surface diode does not have a central hole. It means that centering must be made by the device perimeter or by a cathode centering hole.

The housingless diodes are susceptible to damage caused by particles such as small shavings on the surface during installation. During the diodes installation the protection measures should be taken to avoid solid particles ingress on the molybdenum anode side.

4.2 Parallel connection.

When the application requires higher output power, the capability can be increased by using two or more diodes connected in parallel. The parallel connected diodes require a good symmetric design and accurate mounting to avoid the need for the considerable de-rating of the current through each diode. Even at good conditions, a minimum de-rating of ~10% is recommended such that each diode is utilized to maximum 90% of its capability. The precaution is suggested because there will always be small asymmetries in the transformer connections and the voltage drop in the interfaces will always have some spread. This inherit asymmetries give rise to the unequal current sharing between the devices casing different losses in the diodes. It leads to device overheating and lower reliability that it is expected.

For parallel connection it is recommended to select diodes with less difference threshold voltage $\mathbf{V_{F(T0)}}$.

5 Load cycling capability.

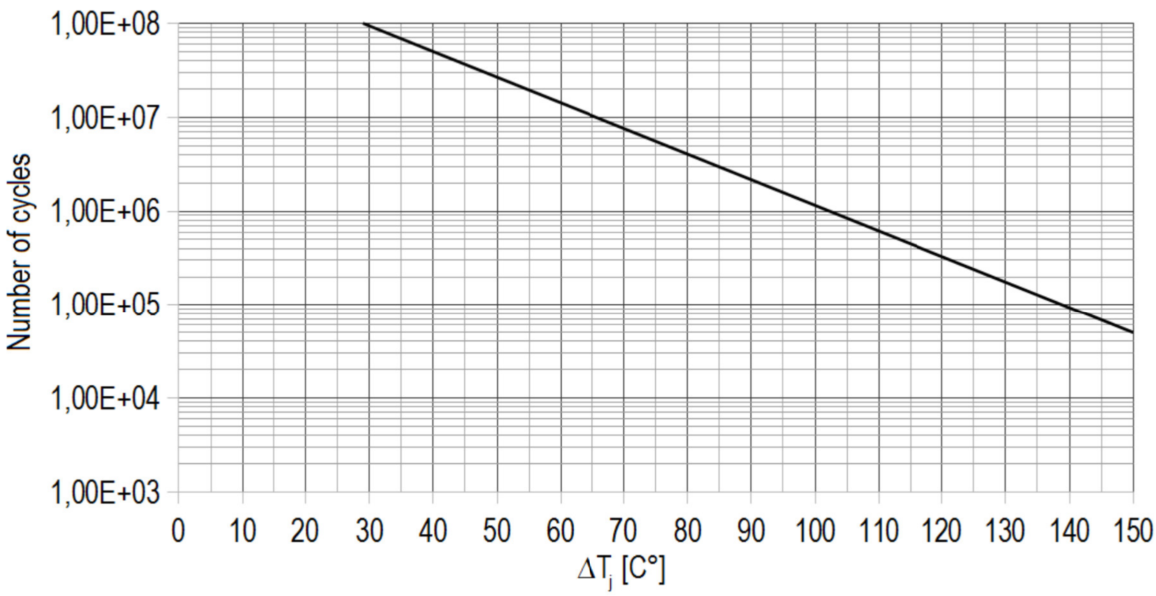

Figure 12. Load cycling capability of diodes as function of ΔT_j.

The dependence was originated by mathematics simulation of data received by testing in high temperature excursion area.

The specific feature of the welding diodes operation is short term cycles of the current pulses passing that leads semiconductor element heating-up and then its cooling down connected with the restrictions on the continuous operation of welding machines (mode «heating up – cooling down»). The result is that the devices are subjected to thermal cycling stress. The determining parameters are peak current, operation time and rest time. All the facts determine strict requirements to static and dynamic characteristics of the device.

During the development of welding diodes for higher load cycling capability the followings methods were applied:

- Cathode layers with special coating;
- Special anode and cathode metallization.