Application Note 5SYA 2013-03

High current rectifier diodes for welding applications

Hitachi Energy has accumulated valuable expertise in designing and manufacturing rectifier diodes for high-current-resistance-welding machines. Concurrent engineering with leading welding equipment manufacturers has resulted in continuous improvements over the years and led to the design of standard and high-frequency rectifier diodes.

1. Introduction

A very low forward voltage drop and thermal impedance of rectifier diodes in a combination with good switching performance make them appropriate for use in medium frequency welding equipment. The diodes can also be used in various low-voltage and high-current rectifier applications. They operate at frequencies beyond 1 kHz with welding currents over 10 kA. Despite these severe conditions, load cycle capability of millions of cycles corresponding to years of a device operation is achieved.

In cooperation with major welding equipment manufacturers for years, valuable experience using diodes to reach optimal reliability and electrical performance was gathered. In this application note, we present important challenges when designing welding rectifiers regarding reliability and cost-effectiveness. The latter are important features of welding diodes. The impact of rectifier diodes on welding equipment performance and mechanical considerations are also discussed regarding reliability and life expectancy.
Hitachi Energy's welding diodes product range is shown in table 1. Data sheets are available at www.hitachienergy.com/semiconductors.

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Standard Part number	V_{RRM}	V_{Fmin}	V_{Fmax}	I_{FAVm}	I_{FSM}	V_{F0}	r_F	T_{jmax}	R_{thjc}	R_{thch}	F_m	Housing
		T_{VJM}= 25 °C, I_F = 5 kA		T_C = 85 °C	10 ms, T_{VJM}	T_{VJM}						
	V	V		V	kA	V	mΩ	°C	K/kW	K/kW	kN	
5SDD 71X0200	200	-	1.05	7110	55	0.74	0.026	170	10.0	5.0	22	X
5SDD 71B0200	200	-	1.05	7110	55	0.74	0.026	170	10.0	5.0	22	B
5SDD 0120C0200	200	-	0.92*	11000	85	0.75	0.020	170	6.0	3.0	36	C
5SDD 71X0400	400	0.97	1.02	7110	55	0.74	0.026	170	10.0	5.0	22	X
5SDD 71B0400	400	-	1.05	7110	55	0.74	0.026	170	10.0	5.0	22	B
5SDD 0120C0400	400	0.83*	0.88*	11350	85	0.74	0.018	170	6.0	3.0	36	C
5SDD 92Z0401	400	-	1.03*	9250	60	0.78	0.031	180	5.6	3.6	22	Z1
5SDD 0105Z0401	400	-	1.01*	10502	70	0.812	0.026	180	5.0	2.5	30	Z2
5SDD 0135Z0401	400	-	0.92*	13500	85	0.758	0.021	180	3.9	2.6	35	Z3

* I_F = 8 kA, T_{VJM}

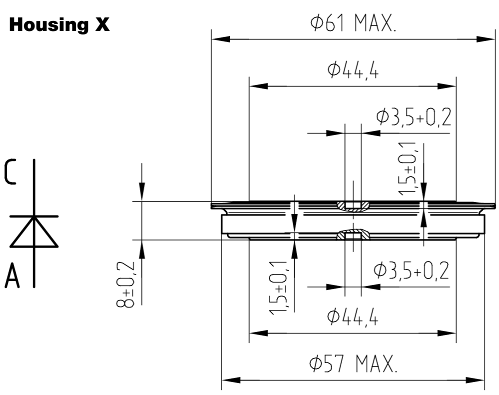
High-frequency Part number	V_{RRM}	V_{Fmax}	I_{FAVm}	I_{FSM}	V_{F0}	r_F	Q_{rr}	T_{jmax}	R_{thjc}	R_{thch}	F_m	Housing
		T_{jmax}, I_F = 5 kA	T_C = 85 °C	10 ms, T_{VJM}	T_{VJM}							
	V		A	kA	V	mΩ	µC	°C	K/kW	K/kW	kN	
5SDF 63B0400	400	1.14	6266	44	0.96	0.036	180	190	10.0	5.0	22	B
5SDF 63X0400	400	1.14	6266	44	0.96	0.036	180	190	10.0	5.0	22	X
5SDF 90Z0401	400	1.13	9041	48	0.98	0.032	200	190	5.6	3.6	22	Z1
5SDF 0102C0400	400	1.14*	10159	70	0.98	0.022	300	190	6.0	3.0	35	C
5SDF 0103Z0401	400	1.20	10266	54	1.00	0.027	230	190	5.0	2.5	30	Z2
5SDF 0131Z0401	400	1.14*	13058	70	0.98	0.022	300	190	3.9	2.6	35	Z3

* I_F = 8 kA

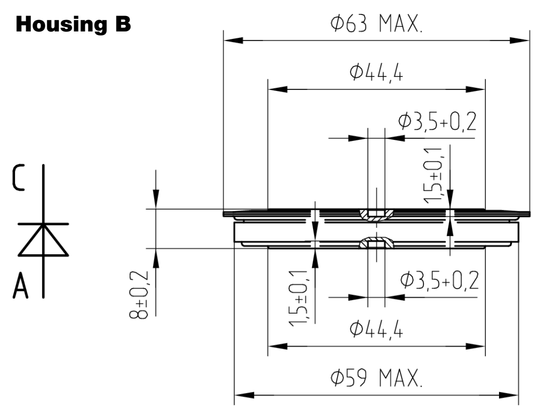
Table 1: Welding diode product range

Hitachi Energy offers three different sizes of encapsulated welding diodes (WDs) and three different sizes of housing-less welding diodes (HLWDs). The outlines of six different housings are

Housing X



Housing B



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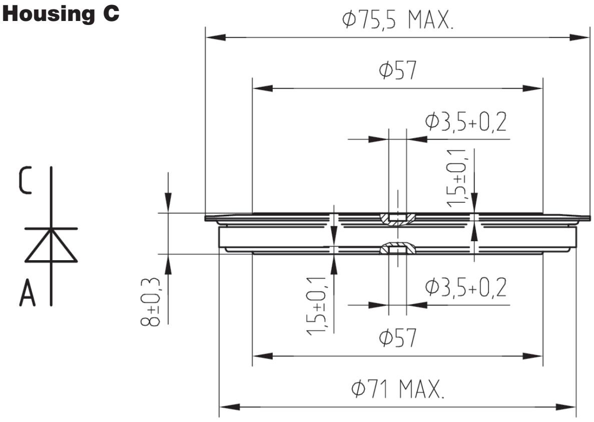
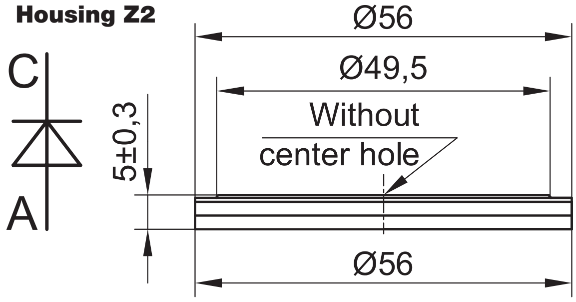
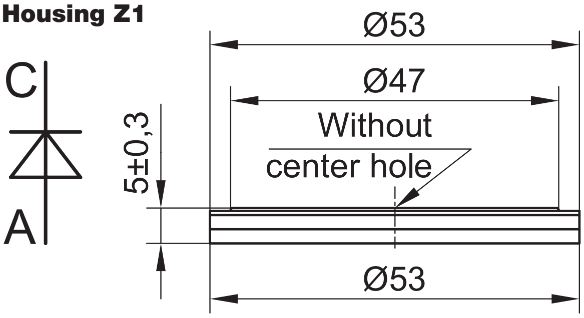
Housing C



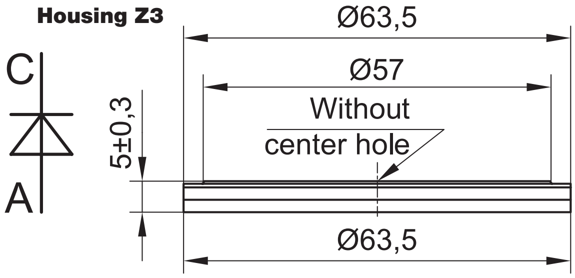
Housing Z2



Housing Z1



Housing Z3



presented below. All dimensions are given in millimeters.
The semiconductor diode chips are alloyed to a molybdenum disk. Due to the low voltage rating, it is possible to use thin silicon to reduce the conduction losses of the devices. In WDs designed in ceramic housings (figure 1, top), the chips are placed inside the hermetic housing between two copper electrodes. Since the requirements for air strike and creepage distance are low, thin housings with low thermal resistance are used. An added advantage is the small size and low weight of WDs, a welcome feature, e.g., for welding equipment mounted on a robot arm in the automotive industry. The HLWDs are constructed with a reduced number of layers to improve their thermal performance. In HLWDs, the silicon chips are covered by a copper electrode on the cathode side which works as a mechanical buffer, the anode side is the hard molybdenum disk which serves as a HLWD case (figure 1, bottom). Although HLWDs are more susceptible to environmental conditions, their advantages are higher current densities, lower weights and geometric sizes compared to WDs.

Fig. 1 The WD in the housing (at the top) and the HLWD (at the bottom)

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The standard welding diodes can operate at frequencies up to 7 kHz. However, their optimal and reliable frequency range is up to 2 kHz. To meet the demands of higher frequencies up to 10 kHz, a new group of high-frequency rectifier diodes with high current capabilities combined with excellent reverse recovery characteristics have been developed. The high-frequency diodes are available both in sealed and housing-less versions.

2. Data sheet user guide

This section aims to guide readers through the welding diode data sheet to understand it properly. The various device parameters which appear in the data sheet are defined and their dependencies are supported by figures where it is appropriate. For explanation purposes, data and diagrams associated with 5SDD 71B0400 are used. However, the guide is applicable to all product range of WDs and HLWDs (table 1). The parameters are defined according to the standard IEC60747.
The key parameters determine the basic voltage and current ratings of the diode. The parameter values are followed by short descriptions of the main features of the welding diode.

5SDD 71B0400

5SDD 71B0400

Old part no. DS 808D-7110-04

Welding diode

Properties

- High forward current capability
- Low forward and reverse recovery losses
- High operational reliability

Applications

- Welding equipment
- High current application up to 2000 Hz

Key parameters

V_{RRM}	=	400	V
I_{FAVm}	=	7 110	A
I_{FSM}	=	55 000	A
V_{TO}	=	0.740	V
r_T	=	0.026	mΩ

2.1. Blocking

Maximum ratings			Maximum limits	Unit
V_{RRM}	Repetitive peak reverse voltage	5SDD 71B0400	400	V
	T_j = -40 ÷ 170 °C	5SDD 71B0200	200	
I_R	Repetitive reverse current $V_R = V_{RRM}$		50	mA

V_{RRM}: The maximum allowable reverse voltage that may be applied to the diode repetitively. The diode must be operated at or below V_{RRM}. Above this level the device will thermally “run- away” and become a short circuit. The rating of V_{RRM} is valid across the full operation temperature range of the diode. The parameter is measured with 10 ms half-sine pulses and a repetition frequency of 50 Hz

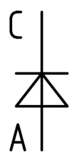
I_{RRM}: The maximum repetitive reverse leakage current given at specified conditions

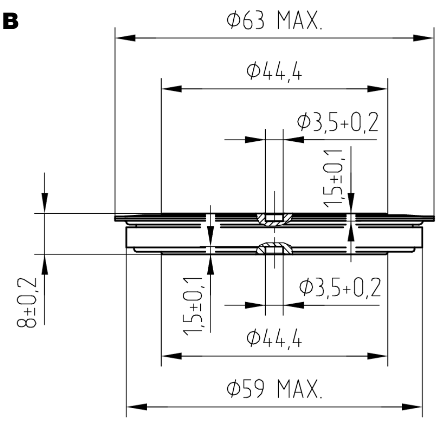
2.2. Mechanical

Type	V_{RRM}
5SDD 71B0400	400 V
5SDD 71B0200	200V
Conditions	T_J = -40 ÷ 170 °C, half sine waveform, f = 50 Hz

Mechanical data		
Fm	Mounting force	22 ± 2 kN
m	Weight	0.14 Kg
D_s	Surface creepage distance	4 mm
D_a	Air strike distance	4 mm

Housing B





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The mechanical part of the data sheet includes the outline drawing of the diode housing where all dimensions are in millimetres, and represent various nominal mechanical parameters.

F_M: The recommended mounting force applied to the device in order to establish the contact pressure for its optimal performance. An application of a lower mounting force leads to an increase of the device thermal impedance and junction temperature excursion, correspondingly. It reduces the diode operation time. On the contrary, an application of higher clamping force may crack the wafer during the load cycling.

a: Maximum permissible acceleration of the device in any direction at given conditions. The value for a clamped device is valid only within the given mounting force limits.

m: The device weight in kilogrammes.

D_s: The surface creepage distance is the shortest path along the housing between the anode and cathode.

D_a: The air strike distance is the shortest direct path between the anode and cathode.

2.3. On-state

Maximum ratings		Maximum limits	Unit
I_{FAVm}	Average forward current T_C = 85°C	7 110	A
I_{FRMS}	RMS forward current T_C = 85°C	11 200	A
I_R	Repetitive reverse current $V_R = V_{RRM}$	50	mA
I_{FSM}	Nonrepetitive peak surge current t_p = 10 ms, V_R = 0 V, half sine pulse	55 000	A
I^2t	Limiting load integral t_p = 10 ms, V_R = 0 V, half sine pulse	15 125 000	A^2s
T_{jmin} –T_{jmax}	Operating temperature range	- 40 ÷ 170	°C
T_{stgmin} - T_{stgmax}	Storage temperature range	- 40 ÷ 170	°C

Unless otherwise specified T_j = 170 °C

Characteristics		Value			Unit
		min	typ	max	
V_{TO}	Threshold voltage			0.740	V
r_T	Forward slope resistance I_{F1} = 5 000 A, I_{F2} = 15 000 A			0.026	mΩ
V_{FM}	Maximum forward voltage I_{FM} = 5 000 A, T_j = 25 °C			1.05	V

I_{FAVM}: The maximum allowable average forward current.

I_{FRMS}: The maximum allowable root mean square (RMS) forward current.

I_{FAVM} and I_{FRMS}: Are defined for 180 ° sine wave pulses of the 50 % duty cycle at the case temperature, T_C.

I_{FSM}: The maximum allowable non-repetitive peak forward surge current.

$\int I^2dt$: The integral of the square of the current over a defined period.

I_{FSM} and $\int I^2dt$: Are determined for a half sine-wave current pulse without a reapplied voltage, V_R = 0. Above the specified values, the device will fail short-circuit. Both parameters are required for protection. The values are introduced for two pulse lengths corresponding to the line frequencies 50 and 60 Hz. In welding applications, however, both the load and fault currents are almost the same and are determined by transformer impedance such that surge capability is seldom of great interest. The dependence of I and $\int I^2dt$ on the single half sine pulse duration at T_{jmax} is shown in figure 4 of the data sheet example.

V_{FM}: The maximum forward voltage drop of the diode at given conditions.

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The threshold voltage, V_{T0}, and the slope resistance, r_T, allow a linear representation of the diode forward voltage drop, and are used to calculate conduction losses of the device, P_T. For a given current, the conduction losses can be calculated using equation 1:

$$P_T = V_{TO} * I_{FAV} + r_T * I_{FRMS}^2$$

where I_{FAV} and I_{FRMS} are parameters described above. To minimise losses, V_{T0} and r_T should be as low as possible. Note, that the linear approximation of the on-state voltage characteristic (see figure 3 of the data sheet example) is valid only within given current limits. Outside these limits, the on-state curve is not linear, and it is preferable to use more complicated models to describe the non-linear shape of the on-state voltage characteristic.

T_j: The operating junction temperature.

T_{jmin} - T_{jmax}: The operating junction temperature range describes the limits at which the device can be used. If the limits are exceeded, the device ratings are no longer valid and there is a risk of catastrophic failure.

T_{stgmin} - T_{stgmax}: The maximum allowable temperature interval for short term storage of the diode without a transport box.

For storage and transportation of the device in the transport box, see environmental specifications 5SZK 9118.

Thermal Specifications			Value	Unit
R_{thjc}	Thermal resistance junction to case	Double side cooling	10	K/kW
		Single side cooling	20	K/kW
R_{thch}	Thermal resistance case to heatsink	Double side cooling	5	K/kW
		Single side cooling	10	K/kW

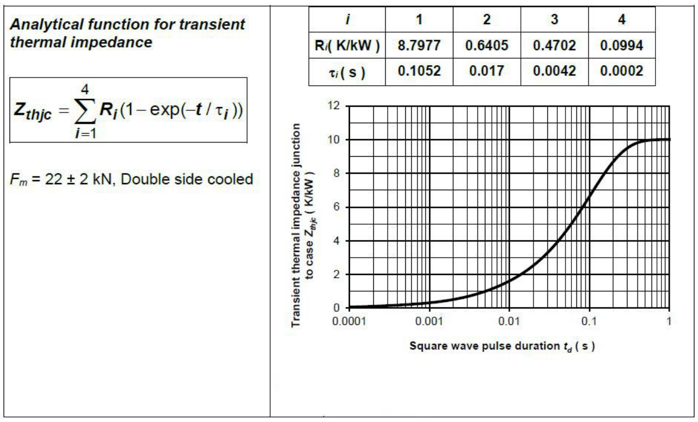

Fig. 2 The dependance of the transient thermal impedance junction to case on square pulse duration for the double side cooling

2.4. Thermal characteristics

R_{thjc}: The thermal resistance as measured from the diode's junction to the baseplate of the diode's case.

R_{thch}: The thermal resistance as measured from the diode's case to heatsink.
The thermal resistances R_{thjc} and R_{thch} are measures of how well power losses can be transferred to the cooling system. The values are given for both cases, the double side cooling, where the device is clamped between two heatsinks, and single side cooling, where the device is clamped to a single heatsink. The temperature rise of the "virtual junction" of the silicon wafer inside the diode in relation to the heat sink, ΔT_{jh}, is given by equation 2.

$$\Delta T_{jh} = P_T * (R_{thjc} + R_{thch})$$

R_{thjc} and R_{thch} should be as low as possible since the silicon temperature determines the current capability of the diode. Furthermore, the temperature excursion of the silicon wafer determines the load-cycling capability and life expectancy of the diode.

Z_{thjc}: The transient thermal impedance. Z_{thjc} emulates a rise of the junction temperature in time when the power dissipation in the silicon junction is not constant. The dependence of Z_{thjc} on the square pulse duration, t_d, in the case of double side cooling is shown in the figure 2 of the data sheet example. This function can be either specified as a curve or as an analytical function with the superposition of usually four exponential terms. The analytical expression is particularly useful for computer calculations and makes it possible to simulate the entire system from junction to ambient. The steady state

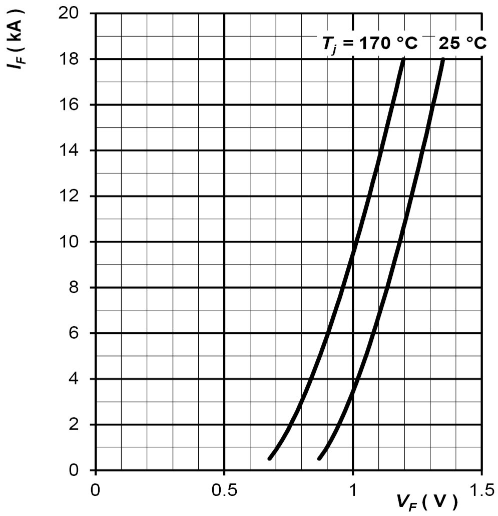

Fig. 3 Maximum forward voltage drop characteristics. The on-state voltage drop of the diode, V_F, as a function of the on-state current, I_F, at given junction temperatures

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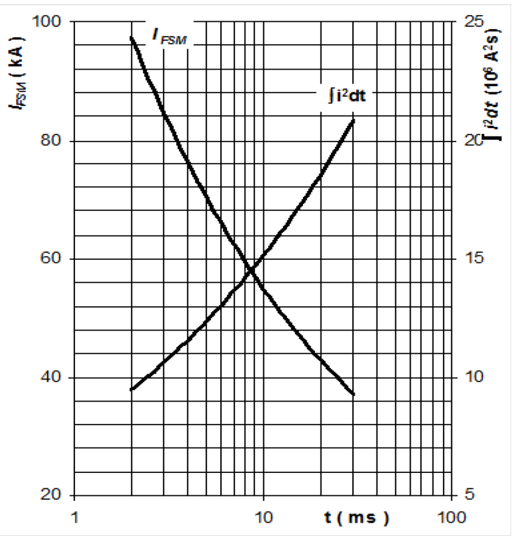

Fig. 4 Surge forward current vs. pulse length, half sine wave, single pulse, V_R = 0 V, $T_j = T_{jmax}$. The non-repetitive surge current limit, I_{FSM}, and the surge current integral, $\int I^2dt$, for different widths of the half sine pulse at T_{jmax}

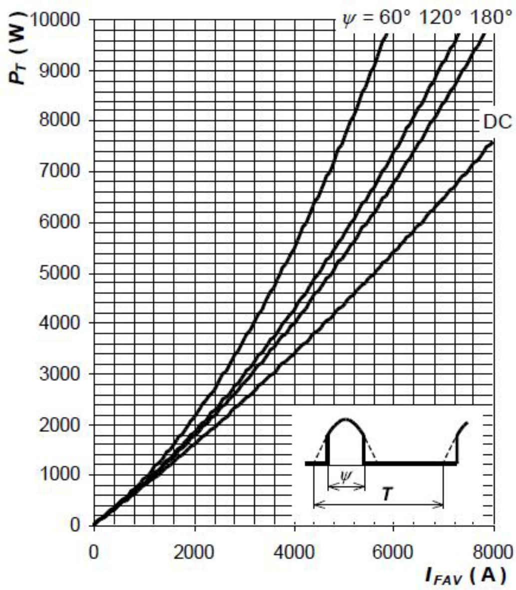

Fig. 5 Foward power loss vs. average foward current, sine waveform, f = 50 Hz

value of Z_{thjc} at t_d ≥ 1 s corresponds to R_{thjc} = 10 K/kW is presented in the table of thermal specifications.

2.5. Power loss and maximum case temperature characteristics

In spite of that, the 50-60 Hz forward current pulse period is not a typical operation condition for the welding diode. In this section, we present characteristics of forward power losses, P_T, calculated for 50 Hz, as these characteristics are considered a standard and are used in power semiconductor data sheets. The diode load characteristics calculated for the most common welding diode application conditions are presented in sections 3 and 4.

Figures 5 and 6 show forward power losses, P_T, as a function of the average forward current, I_{FAV}, for typical sine and square current wave forms. The curves are calculated, based on characteristics of the maximum forward voltage drop, V_{FM} (I_F), at T_{jmax} (which are demonstrated in figure 3) without considering any reverse recovery losses. The curves are valid only for the 50 or 60 Hz operation.

Figures 7 and 8 describe the maximum permissible case temperature, T_C, against the average forward current, I_{FAV}, for typical sine and square current wave forms. The curves are calculated based on the thermal resistance for the double side cooling, for the specified current wave forms and at the maximum junction temperature, T_{jmax}.

Power losses, P_T, the ambient temperature, T_A, given by the application, and the maximum case temperature, T_C, obtained from figures 7 and 8, are used to calculate the diode junction to heatsink thermal resistance, R_{thjh}.

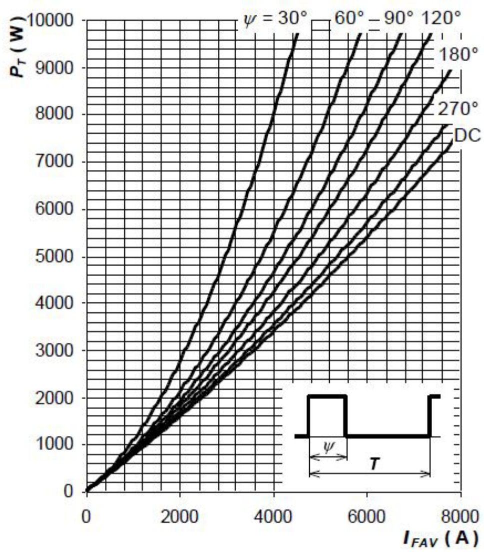

Fig. 6 Foward power loss vs. average foward current, square waveform, f = 50 Hz

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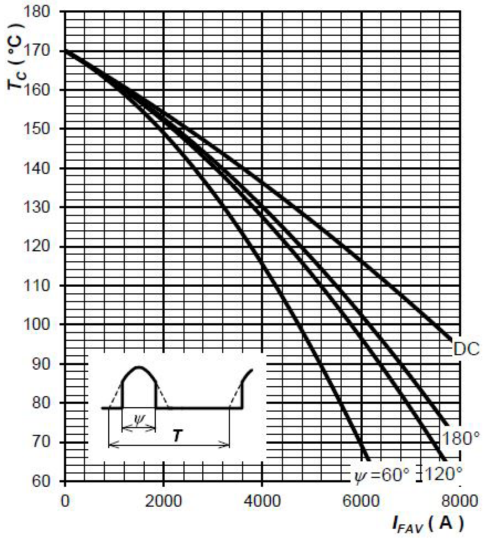

Fig. 7 Maximum case temperature vs. average foward current, sine waveform, f = 50 Hz

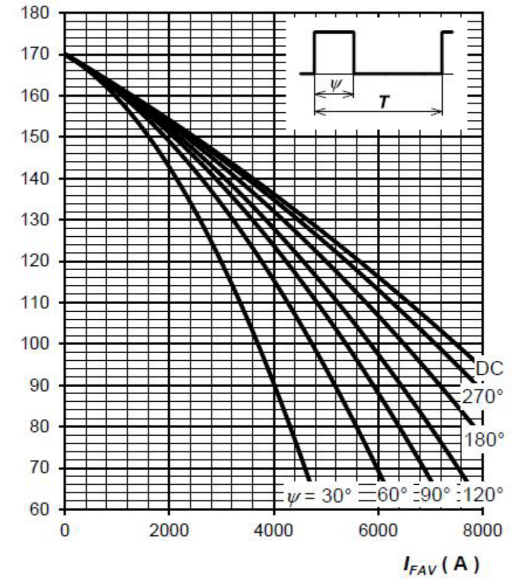

Fig. 8 Maximum case temperature vs. average foward current, square waveform, f = 50 Hz

3. Load cycling capability and welding current

The load cycling capability of the welding diodes is crucial for the choice of application components. Each welding cycle represents a load cycle for the diode used in the application. The load cycling capability is determined by the temperature swing the diode undergoes during the cycle. To keep the temperature swing as low as possible during the welding cycle, the diodes must be designed for lowest possible losses and thermal impedance. Usually, the standard diode specifications do not provide manufacturers with specific information on which rectifier diodes are suitable for a correct rating of a welding machine operating at a given duty cycle and cooling conditions.

The diode lifetime dependence on the junction to heatsink temperature excursion, ΔT_{jh}, is an example of this data deficiency. Figure 9 demonstrates the number of load cycles as a function of ΔT_{jh} obtained experimentally in collaboration with welding equipment manufacturers. The dependence is valid for the whole welding diode product range. The lifetime curve indicates how many cycles it is possible to reach in case of right mounting and proper cooling of diodes under the test. Since the experiment is time consuming, the number of tested devices is limited. This fact could slightly affect the accuracy of the lifetime trend.

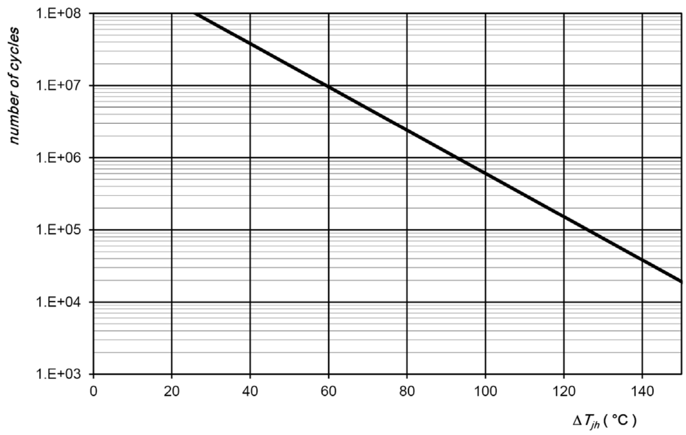

Fig. 9 Achievable load cycling capability of welding diodes produced at Hitachi Energy, Semiconductors, as a function of diode's junction to heatsink temperature excursion, ΔT_{jh}

3.1. The welding cycle and diode load

Figure 10 shows the common diagram of a diode rectifier in the welding application. The simplest connection is of the M2 type with one diode in each leg in order to reduce the number of diodes required for rectification. Since the welding quality is better when using DC instead of AC current, a welding diode rectifier is used to convert the square wave current (usually 1 kHz) to a DC current.

In the automotive industry, a typical welding cycle period, T, consists the welding time, t_d, (typically several hundreds of milliseconds), and the rest time between welding intervals, with a total

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duration usually in the range of 1-10 seconds. The rest time between welding intervals includes the holding time, gun opening time, gun moving time and gun closing time. The duty cycle, ED, is defined by the ratio as in equation 3:

$$ED = \frac{t_d}{T} \cdot 100\%$$

The welding sequence and definition of the duty cycle are shown in figure 11.

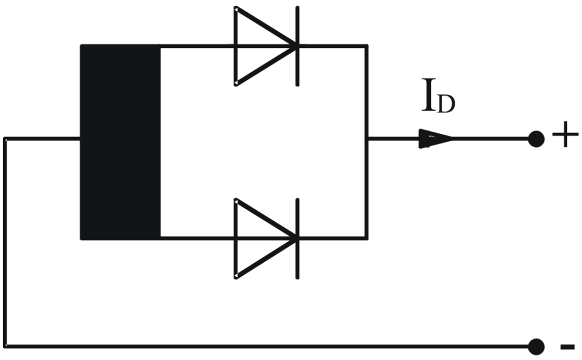

Fig. 10 The diode rectifier diagram, the M2 connection

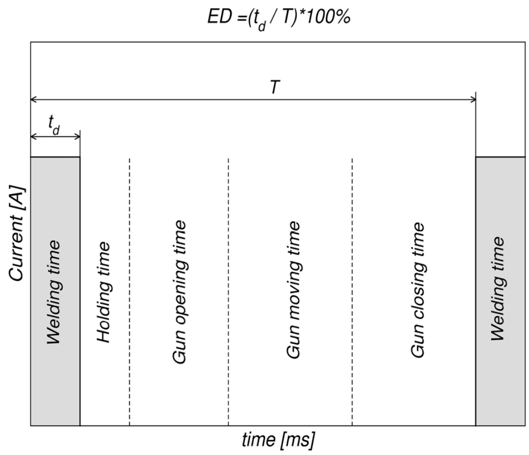

Fig. 11 The definition of a duty cycle for a typical welding application

Based on the diagram in figure 10, the average output DC current during the welding pulse, I_D, is given by the expression in the equation 4:

$$I_D = 2I_{FAV}$$

where I_{FAV} is the maximum average forward current defined in Section 2.

In equation 5, V_{F0} is a threshold voltage, r_T is a forward slope resistance, FF is a form factor ($FF^2 = 2$ for the rectangular pulse shape), and P_{ja} is junction to ambient power loss:

$$I_{FAV} = \frac{-V_{TO} + \sqrt{V_{TO}^2 + 4r_T FF^2 P_{ja}}}{2r_T FF^2}$$

which is determined by the difference of junction and ambient temperatures, ΔT_{ja}, corresponding to the actual temperature rise during one full welding cycle (power "on" and "off") and the transient junction to ambient thermal impedance, Z_{thja} (equation 6):

$$P_{ja} = \frac{\Delta T_{ja}}{Z_{thja}}$$

At high frequencies, the reverse recovery losses have to be accounted for. In figures 5, 6 the calculated dependencies do not include the recovery losses correction, as it is negligible for the 50-60 Hz operation. However, in the case of 1 kHz welding operation, the amount of reverse recovery losses is significant and the total forward power losses have to be reduced by 20 % in the calculation. The total thermal impedance junction to ambient, Z_{thja}, is defined in equation 7:

$$Z_{thja} = Z_{thjh} + Z_{thha}$$

where the transient junction to heatsink impedance, Z_{thjh}, is given in the equation 8:

$$Z_{thjh} = \sum_i R_{thjh}^i \left(\frac{1 - e^{-\frac{t_d}{\tau_i}}}{1 - e^{-\frac{T}{\tau_i}}} \right)$$

In equation 8, *i* is the summation index, t_d and T are the welding time and period, τ is a thermal time constant described in section 2 in the data sheet table of the diode thermal characteristics together with the junction to case thermal resistance, R_{thjc}. R_{thjh} is the thermal resistance junction to heatsink obtained by a normalization of R_{thjc} to a saturated value of R_{thch} chosen for the double side cooling in our calculations.
ΔTja is calculated from the relation

$$\Delta T_{ja} = \frac{\Delta T_{jh} \cdot \left(\sum_i R_{thjh}^i + R_{thha} \right)}{\sum R_{thjh}^i}$$

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where ΔT_{jh} is a constant obtained from figure 9 for the desired number of temperature cycles, R_{thha}, is the resistance to heat flow as measured from the heatsink to ambient. The used R_{thha} of ~ 0.7 K/kW was obtained experimentally by measurements of the thermal resistance of common welding transformers in the M2 configuration.

3.2. Examples of welding curves for 5SDD 71B0400

Examples of dependencies of the welding current, I_D, on the duty cycle, E_D, for the 5SDD 71B0400 diode type are presented in the figure 9. The welding curves are calculated for different temperature excursions, ΔT_{jh} = 40, 60, 70, 80 °C, and various welding pulse widths, t_d = 20, 40, 100, 2000, 1000 ms.
As mentioned earlier, for a desired load cycling capability, i.e., the number of temperature cycles, the allowable temperature excursion, ΔT_{jh}, which represents the cooling system quality, can be estimated from figure 9. After that the maximum allowable welding current, I_D, can be determined for definite welding application parameters, such as the welding pulse width, duty cycle and junction temperature difference. For example, it is required to reach approximately 10 million cycles in the welding application with 5SDD 71B0400, from figure 9 we obtain an allowed ΔT_j = 60 °C. For 100 pulses (t_d = 100 ms) with E_D = 10 %, the allowable welding current I_D = 10 kA (see figure 12 for ΔT_j = 60 °C). In order to reach, with a good probability, the above specified load cycling capability, the mechanical design criteria described in sections 2 and 4, must be met.
In this application note, welding curves are calculated only for the case of the M2 connection (figure 10) with the medium frequency (1 kHz) square wave form. Similar curves can be generated for other connections and wave forms upon request.

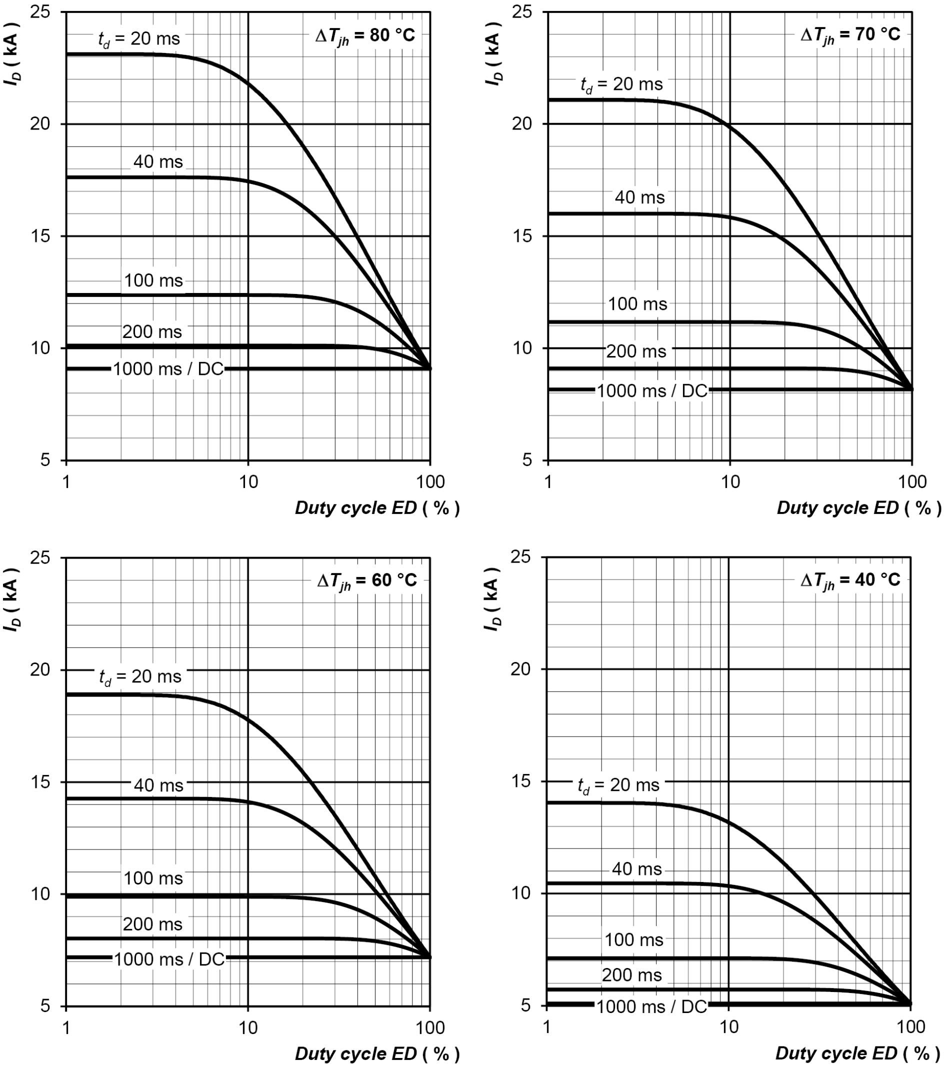

Fig. 12 Current load capacity, cont., DC output welding current with single-phase centre tap vs. duty cycle for different temperature swings ΔT_{jh}, f = 1000 Hz, square wave

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4. Correct welding diode installation

The mechanical design of the rectifier is crucial for its performance. An inhomogeneous pressure distribution is one of the most common reasons of diode failure in welding applications.

4.1. Cooling

Due to the need for high power density encountered in welding applications, the water cooling is the only method used in practice, since other components of the welding system, as, e.g., welding guns, are almost always water cooled. The cooling should be homogeneous over the whole diode contact surface. A single water channel through the center of the heatsink may not be sufficient for heavy-duty equipment and could lead to overheating of the diode rim. The employment of the cooling system with more complicated paths of water channels which would provoke better turbulence is advisable rather than using of simple straight paths (though it may be sufficient for light duty units).

4 2. Clamping and surface treatment

To acquaint with main recommendations related to the device mechanical design and surface treatment, read the document 5SYA2036. In addition to recommendations in 5SYA2036, it has to be mentioned that it is not essential to use thermal greases if the following conditions are fulfilled:

• The heatsinks have a surface finish equal or better in terms of roughness and flatness than those parameters of the diode.

• Heatsinks are galvanically plated with silver-nickel, pure silver, gold or nickel.

• The mounting pressure is homogeneously applied over the whole diode surface and kept stable in the required tolerance.

This recommendation does though not exclude the use of a thin film of a light grease or oil. The interface grease must be carefully chosen for its long-term chemical stability and corrosion inhibiting properties.

4 3. Additional considerations regarding the housing-less welding diodes

The standard HLWDs, 5SDD xxZ0401, and high-frequency HLWDs, 5SDF xxZ0401, do not have a hermetically sealed housing. Therefore, special care must be taken when handling and operating these diodes.

To minimize the environmental impact during transport and storage, HLWDs are delivered in a sealed foil. It is recommended to keep the diode in the foil, and store it at the conditions specified in the environmental specification 5SZK 9118, until the device assembly.

The cathode side of the HLWD has a small copper pole piece that to some extent can act as a mechanical buffer. On the anode side, such buffer is missing since the high hardness molybdenum disc serves as a HLWD case. The molybdenum disc is usually connected directly to a hard copper heatsink. The molybdenum-copper interface has few possibilities to even out imperfections of the surface that leads to the reduction of tolerances regarding roughness and flatness in order to avoid an excessive voltage drop over the interface and fast deterioration of the interface during load cycling.

In addition to recommendations in the application notes 5SYA2036, the following advices should be considered when assembling the HLWD:

• To protect the HLWD from particles and liquids, it is recommended to seal the diode with an o-ring. It is recommended to use o-rings made from materials as Viton® due to their capability to withstand high temperatures and chemicals.

• The anode and cathode of the HLWD do not have a centering hole. It means that the centering must be made on the device perimeter.

• The HLWDs are susceptible to damage caused by particles, such as small shavings on the surface, during load cycling. It can especially occur on the hard molybdenum anode side. Therefore, the assembly should not be carried out in work shop areas where metal is being machined, but in separated places in order to avoid particles to attach to the diode surface.

5. Other application aspects

5.1. Parallel connection

When an application needs higher currents, the capability can be increased by using two or more diodes connected in parallel. Welding diodes made by Hitachi Energy can be connected in parallel, but it requires 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 a maximum of 90 % of its capability. This 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. These inherent asymmetries give rise to an unequal current sharing between devices causing different losses in the diodes. It can lead to device overheating and lower reliability than expected.

The 400 V device types, 5SDD 71X0400 and 5SDD 0120C0400, are better suited for parallel connection, as they have a reduced voltage drop spread in comparison with 5SDD 71X0200 and 5SDD 0120C0200 versions. We do not recommend to use HLWDs for the parallel operation due to their especial properties described in section 4.3.

Returning back to the earlier example with 5SDD 71B0400, if the application needs to approach 10 million cycles that brings the maximum temperature excursion ΔT_{jh} = 60 °C, and the allowable welding current calculated for the regime of 100 ms with a duty cycle of 10 % is 10 kA. Thus, in order to reach 10 million cycle capability using two diodes in parallel, the equipment rating must not exceed 2 * 0.9 * 10 kA = 18 kA.

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5.2. Welding diode turn-off behaviour

The turn-off behaviour of the diode is of relevance to the welding equipment design even if the supply voltage is only in the range of 6 – 20 V. Since the diodes are used without any voltage protection such as an RC-circuit, a device with a “snappy” turn-off behaviour can generate excessive voltage spikes and destroy itself.
The diodes from Hitachi Energy are designed to have a soft turn-off that does not generate voltage spikes in excess of its capability. Figure 13 shows the typical turn-off wave form of a welding diode measured at normal operating conditions with the commutation voltage V_R = 15 V in the M2 configuration. For the normal operation it is important to keep the spike voltage below the rated voltage of the device. In the typical example in figure 13, the diode generates an overvoltage of about 80 V which is less than the diode voltage class with big reserves.

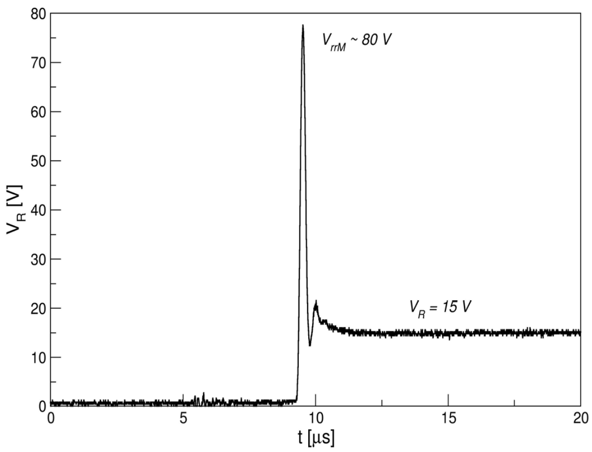

Fig. 13 The typical turn-off wave form of the welding diode at V_R = 15 V

5.3. Welding diode operation at high-frequency

The standard welding diodes produced at Hitachi Energy have been originally designed for operations at line frequencies, but their soft turn-off behaviour makes them well suited for operations at medium frequencies. Today our diodes are mainly utilized at frequencies up to 2 kHz. This frequency range was used for measurements presented in the capability curve in figure 9.
Hitachi Energy's high-frequency welding diodes can be employed in applications with switching frequencies up to 10 kHz (e.g., for aluminium welding) with good results. At frequencies higher than 2 kHz the high-frequency welding diodes still have high current capabilities. The average forward current, I_{FAV}, dependences on the frequency, f, are shown in figure 14 comparing the standard and high-frequency diodes. It is evident that in the case of standard diodes, the average forward current starts to drop at frequencies ~ 2 kHz as a consequence of the reverse recovery losses growth.

The high-frequency diodes with their guaranteed reduced reverse recovery charge, Q_{rr}, and short life time of minority carriers, obtained by the electron irradiation technology, gain low reverse recovery losses at the same frequencies. To calculate the welding currents for high-frequency diodes, as described in section 3.1, the coefficient of the total forward power losses reduction can be estimated from figure 14 (bottom).

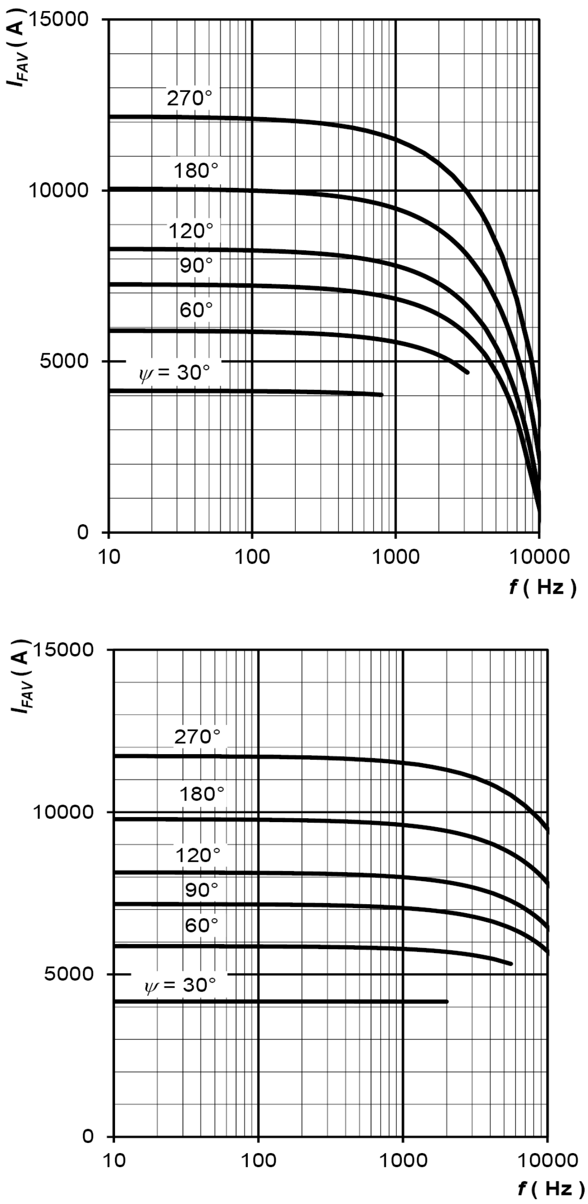

Fig. 14 The average forward current vs. frequency for the standard 5SDD 92Z0400 (top) and high-frequency 5SDF 90Z0401 (bottom) welding diodes, trapezoid waveform, T_C = 85 °C, di_F/dt = ± 2 000 A/µs, V_R = 50 V

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6. References

[1] IEC 60747 “Semiconductor devices”
[2] 5SYA2036 “Recommendations regarding mechanical clamping of high power press-pack semiconductors”
[3] 5SZK9104 “Specification of environmental class for pressure contact diodes, PCTs and GTOs, storage”
[4] 5SZK9105 “Specification of environmental class for pressure contact diodes, PCTs and GTOs, transportation”

7. Revision history

Version	Change	Authors
03		Björn Backlund Ladislav Radvan Nataliya Goncharuk

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