1. Introduction

Triacs are used to control AC mains loads. In many applications, the triac will dissipate enough power to make thermal considerations necessary. The size of heatsink must be calculated and the maximum junction temperature must be predicted. Such thermal design procedures must be followed if long-term reliability of the application is to be assured. **Thermal design and analysis form an essential part of the design and development process.**

The thermal design requires several stages of calculation involving power, thermal resistance, and temperature rise. WAN004 introduces these calculations. Worked examples are included, the data for which is derived from a customer's application or the triac's datasheet.

2. Calculating triac power

Triac power dissipation is influenced by the load current. Full sine wave current (full wave conduction) is assumed since it presents the worst-case condition of maximum triac power dissipation. It also makes for the easiest calculations. If calculations are required for half wave conduction (e.g. for an SCR), please refer to the following subsection: "2.1 How to calculate $I_{T(RMS)}$ and $I_{T(AV)}$ for half wave conduction".

Equation (1)

$$P = V_0 \times I_{T(AV)} + R_s \times I_{T(RMS)}{}^2$$

P is the triac power dissipation (W).

V_0 is the triac knee voltage. This value is given in WeEn data sheets on the I_T / V_T curve. If the value is not available, it can be obtained from the I_T / V_T curve as described in the following subsection: "2.2 How to calculate V_0 and R_s".

$I_{T(AV)}$ is the average load current. This value is calculated from the application's RMS load current using equation (2). (This assumes full wave conduction and sinusoidal load current, which will give worst-case power dissipation.)

Equation (2)

$$I_{T(AV)} = \frac{2 \times \sqrt{2} \times I_{T(RMS)}}{\pi}$$

R_s is the triac slope resistance and this value is given in WeEn data sheets on the I_T / V_T curve. If the value is not available separately, it can be obtained from the I_T / V_T curve as described in the following subsection: "2.2 How to calculate V_0 and R_s".

$I_{T(RMS)}$ is the RMS load current and this value is measured in the application.

2.1 How to calculate $I_{T(RMS)}$ and $I_{T(AV)}$ for half wave conduction

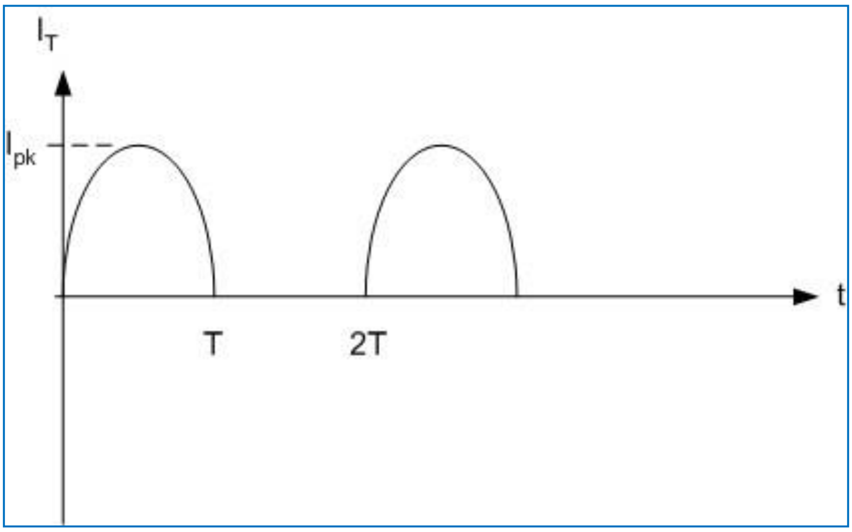

Fig. 1. Half wave conduction – e.g. an SCR at full power on AC mains.

Equations (3), (4) and (5)

$$I_{T(AV)} = \frac{2 \times I_{pk} \times T}{\pi \times 2T} = \frac{I_{pk}}{\pi}$$

$$I_{T(RMS)}{}^2 = \frac{I_{pk}{}^2 \times T}{2 \times 2T} = \frac{I_{pk}{}^2}{4}$$

$$\text{Therefore,} \qquad I_{T(RMS)} = \frac{I_{pk}}{2}$$

2.2 How to calculate V_0 and R_s

If values for V_0 and R_s are not given in the data sheet, it is possible to generate the data. This is done as follows: -

1. Use an enlarged print of the I_T / V_T graph.
2. Taking the $V_{T(max)}$ @ $T_{j(max)}$ curve, draw a tangent that touches the curve at the rated current. A *tangent* is a straight line that touches the curve at one point. Because this is done by eye and may result in some inaccuracy to the slope of the line, it may be simpler and ultimately more accurate to draw a *secant*, which passes through two points on the curve. Points at 0.9x and 1.1x rated current are often used. This will ensure the best accuracy to the slope of the line with minimal shift of the line to the left.
3. The point where the line crosses the V_T axis gives V_0.
4. The slope of the line V_T / I_T gives R_s.
5. An *idealized* example is shown in Fig. 2 for a 1 Amp triac.

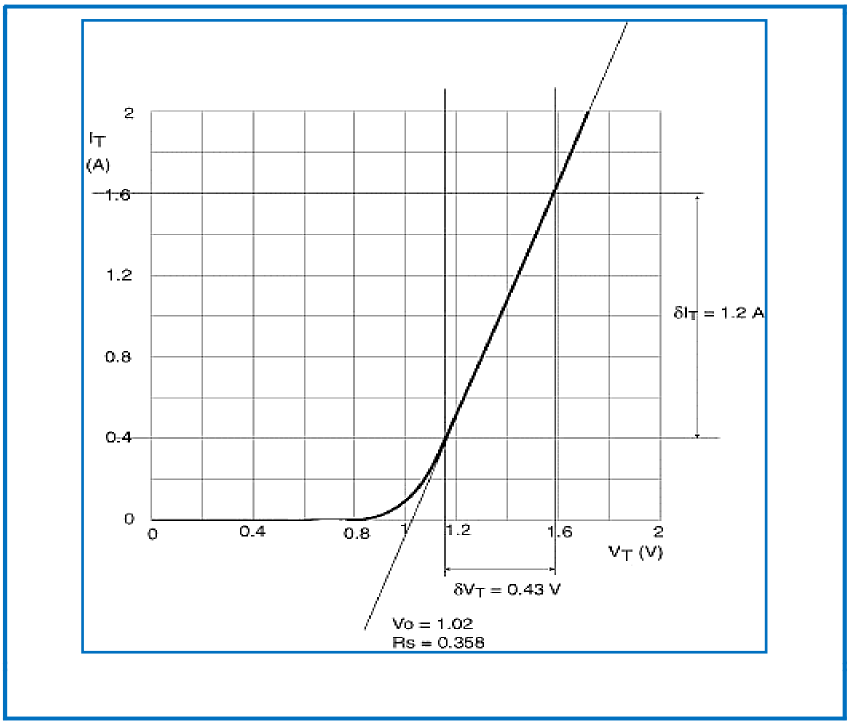

Fig. 2. Using the extrapolated line method to generate V_0 and R_s.

(Note: For worst-case conditions and a hot triac, always use the "max V_T @ $T_{j(max)}$" curve.)

3. Calculating $T_{j(max)}$

$T_{j(max)}$ is influenced by ambient temperature, triac power dissipation and the thermal resistance between junction and ambient. For this Application Note, only the steady state condition will be considered. In the short-term transient condition, transient thermal impedance (Z_{th}) applies. This will always be lower than the steady-state thermal resistance (R_{th}). The transient condition is a lot more complicated and beyond the scope of this guide.

$$T_j = T_a + P \times R_{th(j-a)}$$

T_j – junction temperature (°C).

T_a – ambient temperature (°C).

P – triac power dissipation (W).

$R_{th(j-a)}$ – junction-to-ambient thermal resistance (°C/W).

3.1 Analysis of $R_{th(j-a)}$

Thermal resistance is like electrical resistance in that the total resistance can be broken down into several smaller resistances in series. For the popular package (TO220), $R_{th(j-a)}$ is composed of the following thermal resistances which are also shown in pictorial form in Fig. 3.

$$R_{th(j-a)} = R_{th(j-mb)} + R_{th(mb-h)} + R_{th(h-a)}$$

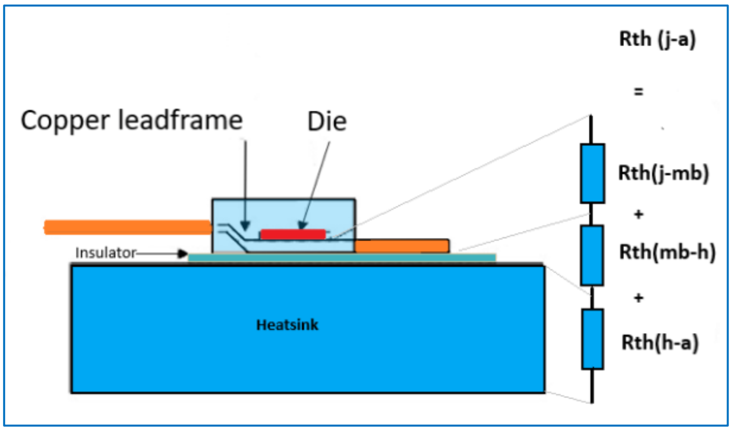

Fig. 3. Composition of thermal resistance for the T0220 package

$R_{th(j-mb)}$ – junction-to-mounting base thermal resistance (°C/W). This is fixed and governed by the device as it is influenced by die size. Refer to the relevant data sheet for the exact value.

$R_{th(mb-h)}$ – mounting base-to-heatsink thermal resistance (°C/W). This is controlled by the end application because it is governed by the mounting method – e.g. with or without thermal grease (heatsink compound), screw or clip mounted, insulating pad material, etc.

$R_{th(h-a)}$ – heatsink-to-ambient thermal resistance (°C/W). This is governed by the end application and is under the control of the equipment designer.

Please note that there are some important caveats in the way the thermal resistance is specified because it depends on the package type and the practicality of isolating a metallic thermal reference point.

1. For plastic packages without a metal mounting base, $R_{th(j-mb)}$ + $R_{th(mb-h)}$ is replaced by a single specification of $R_{th(j-h)}$, since the heatsink is the nearest metallic reference point whose temperature can most easily be measured.

2. For low power plastic packages where a heatsink would not be used, only $R_{th(j-lead)}$ is specified, since the leads are the nearest metallic reference point. Most of the heat would be conducted through the leads to the PCB, with a little radiated directly from the package to ambient. For these packages we would specify a total $R_{th(j-a)}$ with certain assumptions about how the device is mounted on the PCB, which represent typical use.

3. For some surface mount packages without a mounting base (mb) but a *"solder point"* instead, $R_{th(j-mb)}$ is replaced by $R_{th(j-sp)}$. For these packages we would specify a total $R_{th(j-a)}$ when the device is mounted onto a PCB with a specified area of copper.

Table 1 lists some WeEn triac packages and the means of specifying their thermal resistance. Thermal resistance values are given wherever they are fixed by the package type or mounting method. If the thermal resistance is influenced by the triac die, the correct value can be obtained from the data sheet.

Package	Thermal Resistance Specification	Thermal Resistance (°C/W)
T092	$R_{th(j\text{-}lead)}$	60
	$R_{th(j\text{-}a)}$ (PCB mounted, lead length = 4 mm)	150
T0220	$R_{th(j\text{-}mb)}$	See Datasheet
	$R_{th(mb\text{-}h)}$ (clip, with grease, no insulator)	0.3
	$R_{th(mb\text{-}h)}$ (screw, with grease, no insulator)	0.5
	$R_{th(mb\text{-}h)}$ (clip, no grease, no insulator)	1.4
	$R_{th(mb\text{-}h)}$ (screw, no grease, no insulator)	1.4
	$R_{th(mb\text{-}h)}$ (clip, with grease, 0.1 mm mica insulator)	2.2
	$R_{th(mb\text{-}h)}$ (clip, with grease, 0.25 mm alumina insulator)	0.8
	$R_{th(mb\text{-}h)}$ (screw, with grease, 0.05 mm mica insulator)	1.6
	$R_{th(mb\text{-}h)}$ (screw, no grease, 0.05 mm mica insulator)	4.5
	$R_{th(j\text{-}a)}$ (free air without heatsink)	60
SOT82	$R_{th(j\text{-}mb)}$	See Datasheet
	$R_{th(mb\text{-}h)}$ (clip, with grease, no insulator)	0.4
	$R_{th(mb\text{-}h)}$ (clip, no grease, no insulator)	2.0
	$R_{th(mb\text{-}h)}$ (clip, with grease, 0.1 mm mica insulator)	2.0
	$R_{th(mb\text{-}h)}$ (clip, no grease, 0.1 mm mica insulator)	5.0
	$R_{th(j\text{-}a)}$ (free air without heatsink)	100
T0220F (SOT186A)	$R_{th(j\text{-}h)}$ (with grease)	See Datasheet
	$R_{th(j\text{-}h)}$ (no grease)	See Datasheet
	$R_{th(j\text{-}a)}$ (free air without heatsink)	55
IIT0220 (Internally Isolated)	$R_{th(j\text{-}mb)}$	See Datasheet
	$R_{th(j\text{-}a)}$ (free air without heatsink)	60 typ
SOT223	$R_{th(j\text{-}sp)}$	See Datasheet
	$R_{th(j\text{-}a)}$ (free air, minimum pad area, FR4 PCB)	150 typ
T0263 (D^2PAK)	$R_{th(j\text{-}mb)}$	See Datasheet
	$R_{th(j\text{-}a)}$ (free air, minimum pad area, FR4 PCB)	55 typ
T0252 (DPAK)	$R_{th(j\text{-}mb)}$	See Datasheet
	$R_{th(j\text{-}a)}$ (free air, minimum pad area, FR4 PCB)	75 typ
T01292 IIT03P	$R_{th(j\text{-}mb)}$	See Datasheet
	$R_{th(j\text{-}a)}$ (free air without heatsink)	50 typ

Table. 1. WeEn triac packages and their thermal resistance specifications

4. Worked examples

4.1 Vacuum cleaner

A triac is used in a phase control circuit to control the speed of a vacuum cleaner motor. Confirm by calculating for worst-case conditions that the triac's $T_{j(max)}$ of 125 °C will not be exceeded.

Application data: -

The motor power = 1kW max.

The mains supply = 230V RMS.

$$I_{T(RMS)} = \frac{P}{V} = \frac{1000}{230} = 4.35A$$

The triac is clamped to the die-cast metal housing of the turbine, without thermal grease, for heatsinking purposes. Therefore, an insulated triac package is required.

The maximum heatsink temperature is 80 °C.

Calculations: -

A "Hi-Com" triac of 12A is recommended to cope with the inrush current, which can be very high in this application. The suggested triac is BTA312X-600B, which uses the isolated TO220F package, suitable for heatsinking directly to the turbine housing. Its I_{GT} of 50mA is well matched to the drive circuit.

Using equation 2,

$$I_{T(AV)} = \frac{2\times\sqrt{2}\times I_{T(RMS)}}{\pi} = \frac{2\times\sqrt{2}\times 4.35}{\pi} = 3.92A$$

From the data sheet, $V_0 = 1.164V$ and $R_s = 0.027\Omega$.

Using equation 1,

$$P = V_0 \times I_{T(AV)} + R_s \times I_{T(RMS)}{}^2 = 1.164 \times 3.92 + 0.027 \times 4.35^2 = 5.07W$$

Using equation 7,

$$R_{th(j-a)} = R_{th(j-mb)} + R_{th(mb-h)} + R_{th(h-a)}$$

From the data sheet, $R_{th(j-h)} = 5.5$ °C/W without heatsink compound.

$R_{th(h-a)}$ can be regarded as zero, since the turbine housing acts as an infinite heatsink with a maximum temperature fixed at 80 °C under worst-case airflow conditions.

Therefore, $R_{th(j-a)}$ is 5.5 °C/W.

Using equation 6,

$$T_j = T_a + P \times R_{th(j-a)} = 80 + 5.07 \times 5.5 = 108\ ^oC$$

This is below $T_{j(max)}$ of 125 °C and therefore acceptable.

4.2 Refrigerator compressor

A triac is used in an electronic thermostat that controls the ON-OFF switching of a refrigerator compressor. What maximum heatsink thermal resistance can keep the junction temperature of the triac within its $T_{j(max)}$ of 125 °C?

Application information: -

Steady state motor current = 1.4A RMS.

The maximum inrush current = 17A peak in the first half cycle.

The mains supply = 230V RMS.

A surface mounted triac is required for direct soldering to the controller PCB.

The maximum ambient temperature is 40°C.

The triac gate is triggered from a microcontroller with 20mA current sink capability.

Calculations: -

A “Hi-Com” triac of 8A is recommended to cope with the inrush current. The suggested triac is BTA208S-600E, which uses the TO252 (DPAK) package. Its I_{GT} of 10 mA is well matched to the drive capability of the microcontroller.

Using equation 2,

$$I_{T(AV)} = \frac{2 \times \sqrt{2} \times I_{T(RMS)}}{\pi} = \frac{2 \times \sqrt{2} \times 1.4}{\pi} = 1.26A$$

From the data sheet, $V_0 = 1.264$ V and $R_s = 0.0378\ \Omega$.

Using equation 1,

$$P = V_0 \times I_{T(AV)} + R_s \times {I_{T(RMS)}}^2 = 1.264 \times 1.26 + 0.0378 \times 1.44^2 = 1.67W$$

Using equation 6,

$$T_j = T_a + P \times R_{th(j-a)}$$

We already know that T_a = 40 °C and P = 1.67W, and in this case, $T_j = T_{j(max)}$ = 125 °C.

Rearranging the equation gives: -

$$R_{th(j-a)} = \frac{T_j - T_a}{P} = \frac{125 - 40}{1.67} = 51^o C/W$$

Using equation 7,

$$R_{th(j-a)} = R_{th(j-mb)} + R_{th(mb-h)} + R_{th(h-a)}$$

From the data sheet, $R_{th(j-mb)}$ = 2 °C/W. We need to find $R_{th(mb-a)}$.

Rearranging the equation gives: -

$$R_{th(mb-a)} = R_{th(j-a)} - R_{th(j-mb)} = 51 - 2 = 49^o C/W$$

This is effectively the “heatsink” thermal resistance since the PCB is the heatsink in this case.

As an approximate guide this thermal resistance can be obtained with a copper pad area of 500 mm^2 (see WeEn Application Note, WAN003, “Surface mounted triacs and thyristors”).

Please note that the actual thermal resistance will be reduced by other, non-dissipating components in close proximity to the triac, while it will be increased by any components that dissipate power in the presence of the triac. It is essential therefore to measure the prototype to discover the true thermal performance.

4.3 Top-loading (Vertical Axis) washing machine

This machine uses a reversing induction motor that's controlled by two triacs.

Will the $T_{j(max)}$ of 125 °C be exceeded for these triacs if they are operated without a heatsink?

Application data: -

The full load motor power = 300W.

The mains supply = 230V RMS.

$$I_{T(RMS)} = \frac{P}{V} = \frac{300}{230} = 1.3A$$

Isolated triac package is required.

The maximum ambient temperature is 40 °C.

Calculations: -

This application will benefit from 1000V triacs to withstand the high AC mains voltage that the motor imposes across them. A three-quadrant design is mandatory for maximum immunity to false triggering. The BTA208X-1000C or BTA208B-1000C are possible options. These are 8 A, 1000V, Hi-Com triacs with I_{GT} of 35 mA. They use the TO220F "all plastic", "full pack" insulated package and TO263 (D^2PAK) surface mount package respectively.

Using equation 2,

$$I_{T(AV)} = \frac{2 \times \sqrt{2} \times I_{T(RMS)}}{\pi} = \frac{2 \times \sqrt{2} \times 1.3}{\pi} = 1.17A$$

From the data sheet, V_0 = 1.216 V and R_s = 0.0416 Ω.

Using equation 1,

$$P = V_0 \times I_{T(AV)} + R_s \times {I_{T(RMS)}}^2 = 1.216 \times 1.17 + 0.0416 \times 1.3^2 = 1.49W$$

Using equation 6,

$$T_j = T_a + P \times R_{th(j-a)}$$

We already know that T_a = 40 °C and P = 1.49W.

From the data sheet, $R_{th(j-a)}$ for the TO220F package in free air is 55 °C/W.

$$T_j = 40 + 1.49 \times 55 = 122^{o}C$$

This is below the $T_{j(max)}$ of 125 °C. Therefore, the triacs can be operated without heatsinks.

4.4 Power tool

A heavy-duty electric drill uses a universal (brush) motor whose speed is controlled by a half-wave phase control circuit. Calculate the maximum power dissipation in the Silicon Controlled Rectifier and calculate the heatsink thermal resistance required to maintain the junction temperature below $T_{j(max)}$.

Application data: -

The full load peak motor current = 5A.

A surface mounted triac is required for mounting within the trigger switch.

The maximum ambient temperature is 50 °C.

The SCR is air-cooled from the motor cooling fan.

Calculations: -

The BTH151S-650R is recommended. Its 12 Amp RMS rating and ruggedized internal construction provide a high repetitive surge guarantee for the best reliability in repetitive overload situations. It uses the TO252 (DPAK) package.

Using equation 3,

$$I_{T(AV)} = \frac{I_{pk}}{\pi} = \frac{5}{\pi} = 1.59A$$

Using equation 5,

$$I_{T(RMS)} = \frac{I_{pk}}{2} = \frac{5}{2} = 2.5A$$

From the data sheet, V_0 = 1.06V and R_s = 0.0304Ω.

Using equation 1,

$$P = V_0 \times I_{T(AV)} + R_s \times {I_{T(RMS)}}^2 = 1.06 \times 1.59 + 0.0304 \times 2.5^2 = 1.88W$$

Using equation 6,

$$T_j = T_a + P \times R_{th(j-a)}$$

We already know that T_a = 50°C and P = 1.88W, and in this case, $T_j = T_{j(max)}$ = 125°C.

Rearranging the equation gives: -

$$R_{th(j-a)} = \frac{T_j - T_a}{P} = \frac{125 - 50}{1.88} = 39.9^o C/W$$

Using equation 7,

$$R_{th(j-a)} = R_{th(j-mb)} + R_{th(mb-h)} + R_{th(h-a)}$$

From the data sheet, $R_{th(j-mb)}$ = 1.8°C/W. We need to find $R_{th(mb-a)}$.

Rearranging the equation gives: -

$$R_{th(mb-a)} = R_{th(j-a)} - R_{th(j-mb)} = 39.9 - 1.8 = 38.1^o C/W$$

This "heatsink" thermal resistance covers the steady-state condition and is easily achievable with a small degree of airflow through the switch module.

Revision history

Rev	Date	Description
v.1	20050810	initial version
v.2	20190501	new company update
v.3	20190718	format update
v.4	20190805	worked examples update
v.5	20210323	format update, V_0 and R_s calculation clarification, Table. 1. Update
v.6	20220816	correction to $I_{T(AV)}$ formula page 1

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