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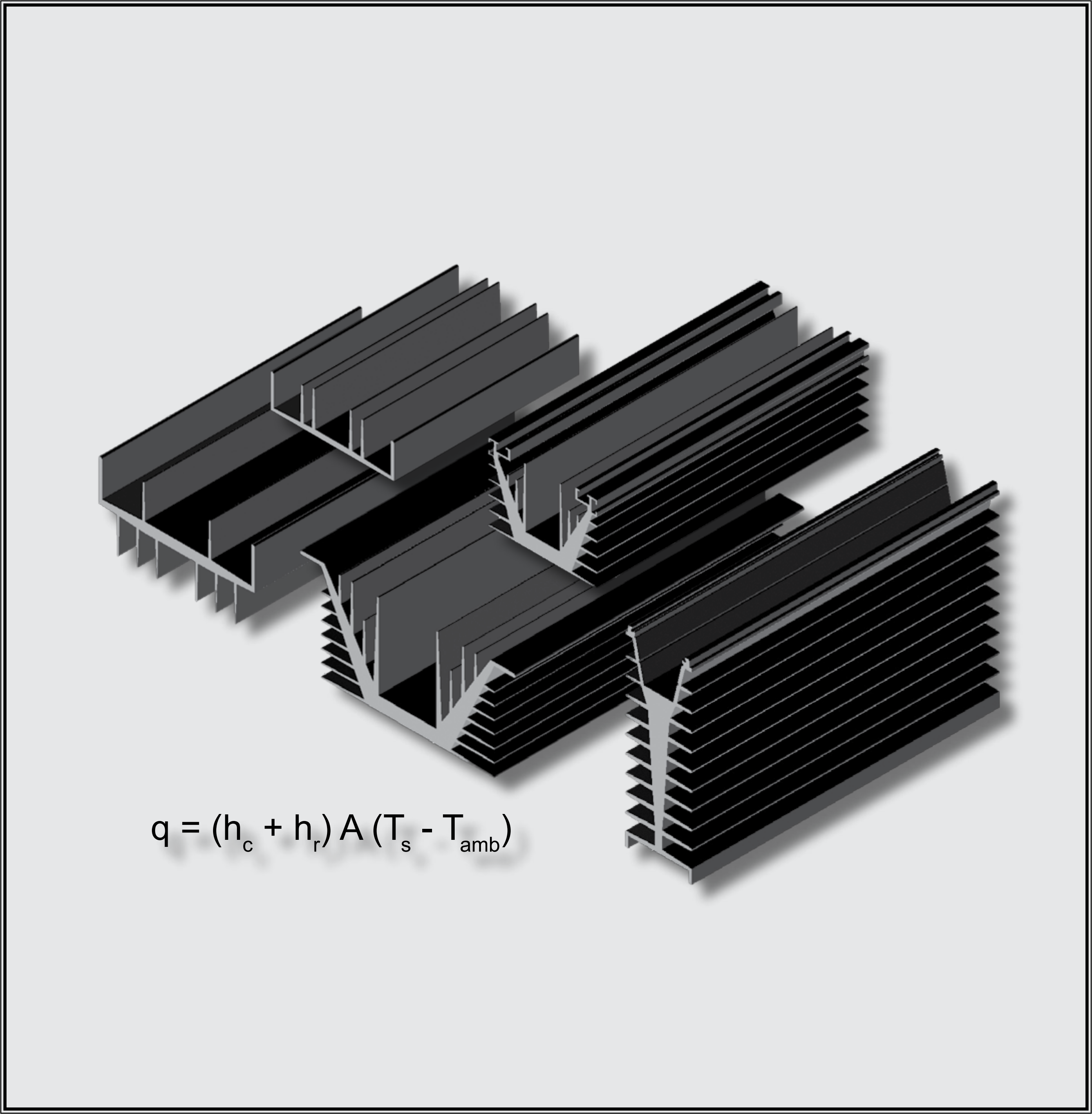
Application Note 10-18

PAYNE
ENGINEERING

TEMPERATURE CONSIDERATIONS FOR SCR CONTROLS



TEMPERATURE CONSIDERATIONS FOR SCR CONTROLS

Thyristor controls - more commonly called SCR control - are being widely used for control of electric heat and electric motors. For the most part, they are replacing electromechanical controls such as contactors, autotransformers, and starters because of their vastly improved performance and reliability. However, there are 3 basic rules which must not be overlooked in the application of SCR controls:

1. Positive, non-destructive over-voltage protection must be provided.
2. Load fault over-current protection must be provided
3. Heat transfer of the nominal 2 watts per amp per phase (generated by all silicon power semiconductors) must be provided.

   The following addresses the last requirement in some detail.

HEAT GENERATOR

It is not widely understood that all silicon semiconductors have a forward voltage drop in the conduction direction which, for power silicon, typically ranges from 1 volt to more than 2 volts. This voltage drop multiplied by the amount of RMS current flow through the devices results in watts - sometimes kilowatts - of heat at the semiconductor mounting point.

$$\text{Watts} = \Delta V_{drop} \times I$$

If this heat is concentrated at the semiconductor and not allowed to dissipate, the temperature of the device will very rapidly rise to levels far greater than an SCR's 125°C maximum rating* (for a diode, this temperature is typically 200°C) causing instant destruction.

The proper international nomenclature for this forward conduction drop is:

Diodes: VFM = Maximum peak forward voltage drop @ rated current
SCR's VTM = Maximum on-state voltage @ rated current

Referring to the typical AC switch or DC bridge arrangements of various solid state power circuits (see Payne Engineering Application Note 8-18), it is quite evident that the equipment designer must provide a heat transfer mechanism to dissipate literally thousands of watts on any given control assembly. A 600HP, three phase motor starter, for example, would generate over 3600 watts of heats to be dissipated, while a much simpler 3kW heat seal control would need to rid itself of only 30 watts or so.

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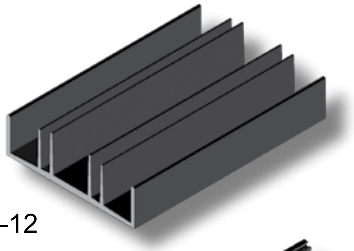
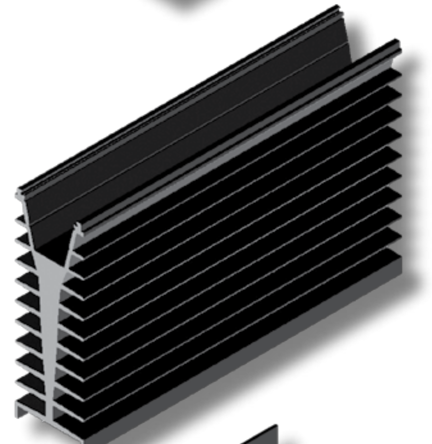
*Typically, 125°C is a true maximum SCR temperature with allowable current at 0 amperes.

HEAT EXCHANGER DESIGN



26A-12



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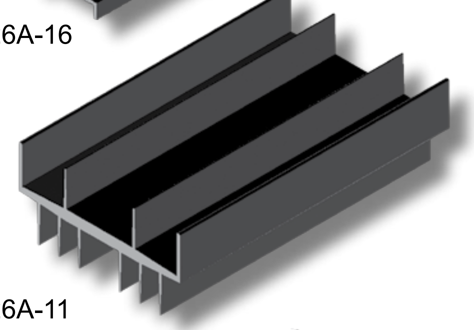

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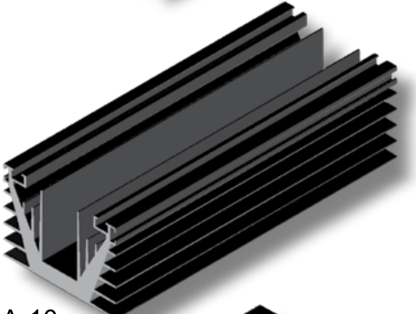

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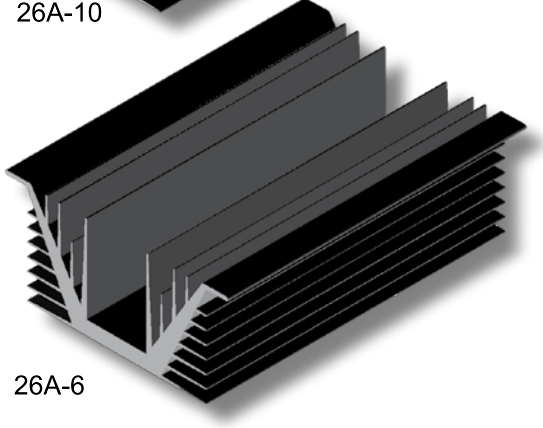


26A-6

Popularly known as “heatsinks”, semiconductor heat exchangers are made in a variety of shapes and sizes, both air cooled and liquid cooled. For purposes of this paper, only aluminum air cooled heatsinks will be considered in detail. The future for wide, economical usage of solid state power controls requires a lightweight but compact and reliable design with MBTF (mean time between failures) measured in years. This requirement immediately precludes fan cooling of closely spaced fin heatsink designs which can fill up and be clogged with dirt and soot in a few years.

The Model 26A Series of aluminum heatsinks has been painstakingly developed since 1961 to provide natural convection and radiation cooling of power semiconductors from 10 amps/phase to 600 amps/phase, utilizing isothermal cross-sections with a design goal of 50^{o}C maximum rise under actual control operating conditions.

TABLE 1

MODEL #	SHAPE	AMPERES	MAX ^{o}C/watt	SP WGT lb/ft
26A-12	4” channel beam	50-80	1.0	1.44
26A-16	6” channel beam	50-120	.39	5.4
26A-11	6” channel beam	150	.4	3.60
26A-10	4” flat puck	250-450	.32	4.50
26A-6	7.5” flat puck	450-1200	.15	7.90

Extension of the 26A-6 and the 26A-10 designs to accommodate the range from 600A to 1200A, utilizing only the standard 4 1/2”(110mm) 100 cfm “muffin” fans, was done to ensure that the fan replacements could be easily found anywhere in the world. The wide, natural convection fin spacing has proven to be completely resistant to dirt buildup since their first service in the early 1970’s.

For the relatively low temperature vertical surface type heat exchanger of the above, the heat transferred by convection is substantially larger than that transferred by radiation. The total can be calculated by the following:

Eq. 1.0

$$\mathbf{q = (h_c + h_r)\, A\, (T_s - T_{amb})}$$

where:
q = watts
h_c = convection heat transfer coefficient (watt/cm^2 ^{o}C)
h_r = radiation heat transfer coefficient (watt/cm^2 ^{o}C)
A = heat transfer surface area (cm^2)

CONVECTION

Experimental studies of convection heat transfer coefficients from vertical surfaces took place in the early years of the 20th century, building up a reasonably reliable base of data. Fig. 1 describes in some detail the local upward air velocity and air temperature gradients in front of a 30cm long heated vertical plate as measured by Schmidt[2]. Fig. 2 is an interferometer photograph by Kennard[3], illustrating the natural convection air stream approaching a vertical plate 30°C hotter than room ambient air.

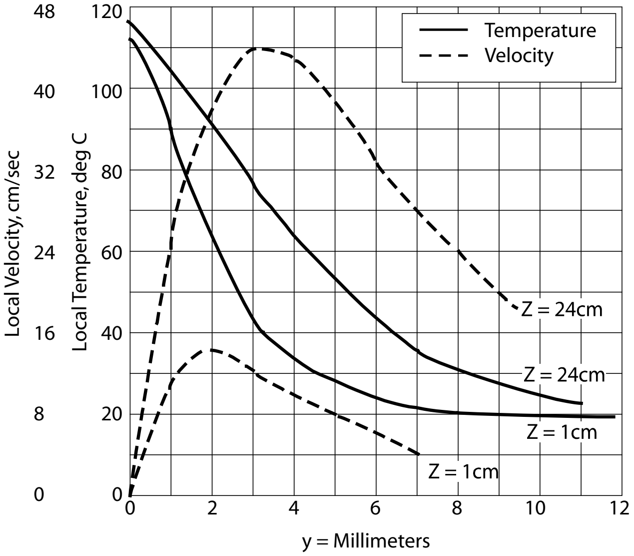


Fig. 1

The relatively complex equations and data acquired by these early researchers can be simplified for our low temperature laminar flow to the following:

Eq. 1.1

$$h_c = K_F \left[\frac{(T_S - T_{amb})}{L}\right]^{.25}$$

where:

K_F = fin constant
L = vertical length of fin (cm)
T_S = fin surface temperature °C

Further experiments by Payne Engineering in the late 1960’s indicated a very high sensitivity of the fin constant K_F, to any form of blockage which could create turbulent flow disturbances to the heatsink. It was found that these disturbances seriously degrade the cooling ability of the heatsink and further that additional fins and/or heatsink mass did not alleviate the situation. The most effective fin designs were determined to be those that allowed the highest velocities, approaching 1 meter/sec per Fig. 1, over the greatest wetted area.

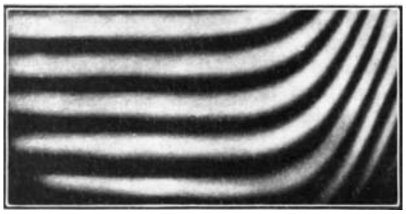


Fig. 2 - Interferometer photograph demonstrating laminar airflow.

RADIATION

The heat emitting capability of a black body depends on its temperature only, and the Stefan-Boltzmann Law[1] defines the radiant heat output of a perfectly black body as $q = 5.67 \times 10^{-8} T_s^4$ watts/m^2. From this relationship, the radiant heat transfer coefficient can be stated as:

Eq. 1.2

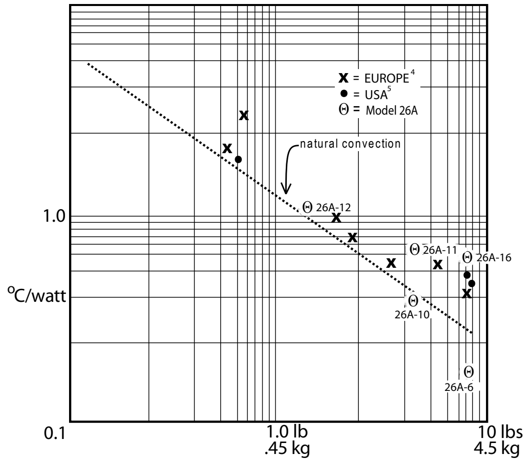
$$h_r = .223 \times 10^{-10} e(1-F) \left[\frac{T_S + T_{amb} + 273}{3}\right]^3$$

where:

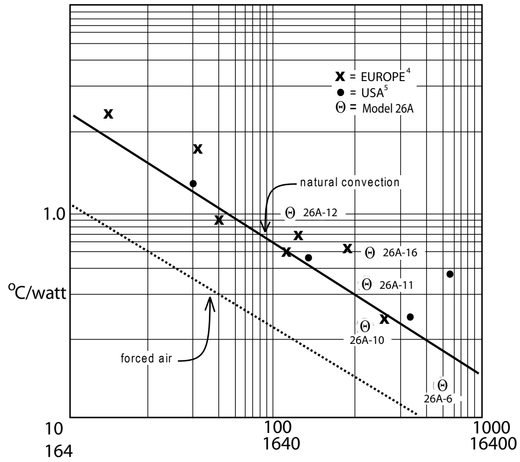
e = surface emissivity
F = fin shield factor

For multiple fin heatsinks, with closely spaced fins radiating into each other, calculation of shielding factor F is unreliable at best. Experimental tests, including tests in an evacuated chamber, indicate that convection heat transfer contributes approximately 85% and radiation 15% of the total heat dissipated over a semiconductor ampere range from 10A to 450A.

EFFICIENCY



°C/watt @ 50° C rise vs. heatsink weight (Al)
(Θ) lb s.
kg.



Thermal resistance, Θ @ 50° C rise vs. Heatsink Volume
in^3
cm^3

The effectiveness of heatsink designs is normally expressed in °C temperature rise of the semiconductor case for a given wattage input. Rearranging Eq. 1.0 allows one to create a thermal resistance coefficient Θ in °C/watt for any heatsink design:

Eq. 1.3

$$\Theta = \frac{1}{(h_c + h_r) A} = \frac{^{o}C}{watt}$$

where:

A = heatsink wetted area (cm^2).

Fig. 3 details the above vs. heatsink volume and weight for commercially available heatsinks in Europe and the USA. The equipment designer can increase wetted area A with only decreasing returns in order to lower his thermal resistance. To achieve Θ values less than .10° C/watt for cooling requirements of 600 amp and larger controls requires forced air or liquid cooling. The 26A-6 design 100 cfm “muffin fans” can achieve a Θ value of .075, half the best natural convection value shown.

ENCLOSURE CONSIDERATIONS

The classical electrical enclosure over the years has normally been a closed, dust-tight box whose design has been primarily dictated by the sensitivity of electromechanical controls to dust, dirt and corrosion. Heat and/or temperature buildup were rarely serious considerations with such controls. However, the advent of solid state controls for both logic and power handling duty mandates a different design approach to electrical enclosures.

1. Dust, dirt and corrosion are not serious concerns for a properly designed solid state power control.
2. Temperature extremes, however, can be catastrophic for any semiconductor device as well as its associated electronic components.

The 50° C ambient temperature, which is a generally accepted international standard, is a very demanding requirement when one adds a 50° C temperature rise to the semiconductor case and is left with only a 25° C working range to the 125° C "zero current" rating of normal SCR's. Of course, for a silicon diode this is no problem, since most diode designs are flat-rated to at least 130° C and their "zero current" does not occur until 200° C. Obviously, the more diodes one can substitute for SCRs, the more reliable will be one's control. In addition, many electronic components have only a 1000 hour life at a typical specification temperature of 65° C.

Therefore, it is clear that the end user must carefully consider his electrical enclosure for proper internal cooling - usually by convection ventilation to the outside ambient. Low power solid state controls of less than 80 amps per phase or three phase motor starters up to 50 HP can be successfully installed in conventional sealed dust free enclosures with derating and/or with an isolated heatsink enclosure design. However, note Fig. 4 where a typical sealed enclosure of substantial size (30 x 20 x 10 in. or 76 x 51 x 25 mm) has been tested for it's internal ambient temperature for various power control outputs. Even a relatively benign 60 amp three phase external load has caused the inside ambient to exceed 50° C with only a 22° C outside enclosure ambient.

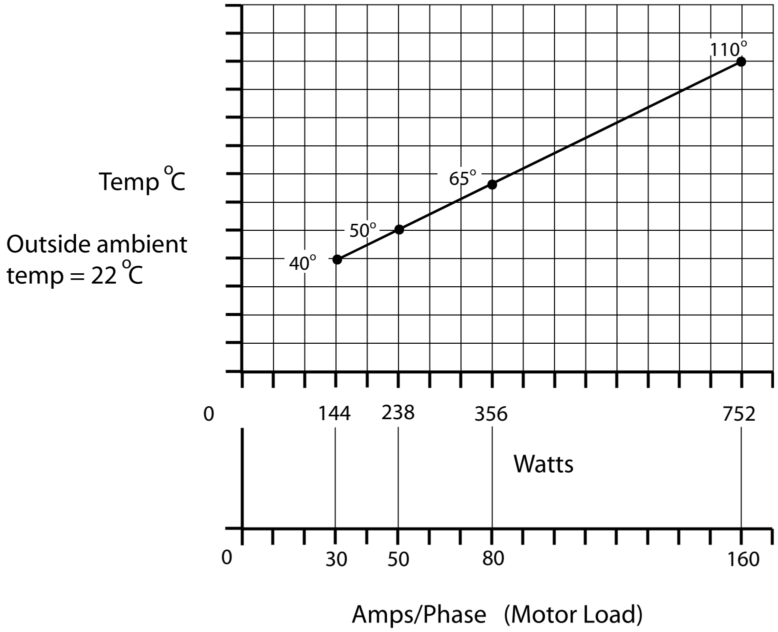


Fig. 4. Inside temperature of dust-tight NEMA 12 steel enclosure (30 x 20 x 10 in.) vs. semiconductor watt losses.

The same enclosure with ventilation screens* on the bottom and each top side would then have only a small increase of it's inside ambient temperature simply because outside ambient air is allowed to flow freely - using the buoyancy forces of natural convection - up through the bottom enclosure screen past a vertically mounted solid state heatsink and out the top vents.

Finally, one should not be complacent about simply using a larger sealed enclosure and/or employing internal fans to cool the solid state control. Fans add even more air friction source energy to the enclosure ambient and may only delay the inevitable over-temperature condition when the silicon forward drop wattage is not properly dissipated to the surrounding ambient.

*Typically, 10 in^2 (65cm^2) of inlet area (and equal outlet area) for every 50 amp phase is usually sufficient in most industrial plant applications.

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