Introduction of Thermoelectric Coolers
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1 INTRODUCTION THERMOELECTRIC COOLING

1.1 General
Thermoelectric cooling provides an alternative solution to the common compressor and absorber cooler. Thermoelectric coolers are used especially if small cooling power is needed (up to 500 W)

Benefits of thermoelectric coolers:
- small size
- light in weight
- no fluid
- independent from the working position
- high reliability
- exact temperature control
- heating by changing the direction of the current

2 WHAT IS A THERMOELECTRIC MODUL
The core piece of a thermoelectric cooler is the thermoelectric module.

A thermoelectric module is an electrical module, which produces a temperature difference with current flow. The emergence of the temperature difference is based on the Peltier effect designated after Jean Peltier. The thermoelectric module is a heat pump and has the same function as a refrigerator. It gets along however without mechanically mobile construction units (pump, compressor) and without cooling fluids. The heat flow can be turned by reversal of the direction of current.

2.1 Peltier-Effect
By connecting 2 wires of different electrically leading materials at the 2 ends and by applying additionally a voltage, a current flows, which transports heat of one junction point to the other. In the consequence one junction point becomes cold and the other one warm.

For thermoelectric modules materials are applicable with a high electrical conductivity and a small thermal conductivity. Unfortunately good electrical conductors are also good heat conductors. The best efficiency is obtained with semiconductors.
2.2 Principle structure of a thermoelectric module

Thermoelectric modules consist of 2 different electrically leading materials. They are alternating electrically interconnected and mechanically arranged in such a manner that the junction points are alternating on one level.

2.3 Thermal flows in a cooler

On the hot side the net heat from the cold side and the power required to pump this heat must be transferred to the environment.

\[ Q_h = P_{el} + Q_c \]

By changing the direction of the current the heat flow changes too, from the cooling mode into the heating mode.
3 THERMOELECTRIC COOLERS

3.1 Basic configuration

Heat sinks or liquid cooling plates are used as heat exchangers.

3.2 Types
Depending on the used heat exchangers the cooling units are distinguished:
- air to air
- air to fluid
- fluid to fluid
- direct to air (cooling plate to air)

Examples:

- air to air cooler
- fluid to fluid cooler
- fluid to air cooler
3.3 Construction of an air to air cooler

Air-to-air coolers work also without fans. With fans, the cooler has a higher performance.

3.3.1 FAN
The fans are the only mobile parts of the cooler. Possibly one would like to leave out the fans. You have to consider that a heat sink works 3 times better with fan than without.

3.4 Cooling plate
Normally a heat source delivers the heat to the ambient air. To avoid overheating, the ambient air must often be cooled. You can cool more efficient, by removing the heat directly from the source. If possible one uses a cooling plate (direct-to-air cooling unit) in place of the air-to-air cooling unit.
3.5 Modularity
Cooling units have modular structures. Therefore it can be useful, instead of using one large, to use 2 small cooling units.

Example:

4 CHARACTERISTIC VALUES OF A COOLER
4.1 Power supply
4.1.1 VOLTAGE
Basically the cooling capacity depends on the current. The cooling units are usually built for using at constant dc voltage e.g. 12V, 24V. We advice you to reduce the maximum ripple to 10%, preferably to 5% for an optimal operation.

If the voltage rises over the nominal value, the increase of the cooling performance is small or even declines and the efficiency drops intense.

If the voltage is reduced, the maximum temperature difference cannot be achieved any more. The cooling power reduces in equal measure, but the COP rises (efficiency, see chapter 4.3). The use of adjustable DC supplies makes a rough adjustment for the temperature possible. If an exact temperature is required, a controller must be used (see chapter 6).

Please note that the fans have always to be operated with rated voltage.

By reversal of the polarity one heats instead of cools. So the cooling unit can be used as air conditioner. Please note that the polarity of the fans may not be inverted (=> separate supply).

4.1.2 CURRENT
The initial current is larger than the current in continuous operation. Consider this for the dimension of the power supply. With increasing temperature difference at the cooling unit the current decreases.

4.2 Relation between temperature difference and cooling power
Data such as 300W cooling unit, maximal cooling power 250W, operating cooling power 180W say little about the efficiency of a cooling unit. The cooling performance depends on the temperature difference. Please see in the following diagram:
4.3 Efficiency
The efficiency of a thermoelectric cooling unit is indicated as the COP (Coefficient of Performance). It is defined as follows:

\[ \text{COP} = \frac{Q_c}{P_{el}} \]

\( Q_c \): cooling power
\( P_{el} \): electrical power

The COP depends on the temperature difference. The higher the temperature difference the smaller is the COP.

4.4 Operating temperature range
The operating temperature range of a cooling unit is determined by the thermoelectric modules and the fans.

There are thermoelectric modules for operating temperatures up to 200°C. At low temperatures the cooling power decreases strongly due to the material.
Effectively the operating temperature range is limited by the fans. Starting from 60°C the life cycle reduces with increasing temperature.

4.5 Ingress protection (IPx)
The reachable ingress protection depends on the fans. They are exposed to the environment. Fans are available with ingress protection IP67. The thermoelectric modules can be sealed. The cooling units can be developed in such a way that no water or humidity enter the cooling unit. Standard cooling units meet IP54.

4.6 Reliability
Thermoelectric cooling units are considered, construction based, as very reliable. With inappropriate treatment the following errors can occur:
- Overheating of the thermoelectric module because of insufficient heat dissipation (heat sink, fan) on the hot side or too high voltage.
- Quick or large changes of temperature on the hot and/or cold side.

One may not exceed the maximum operating temperature, defined in the specifications, in every case. An excess of the maximum temperature leads to a decrease of cooling power or even to a loss. The temperature range can be extended by the choice of suitable thermoelectric modules. If a cooling unit is used in the cycling mode, (heating / cooling), special thermoelectric modules should be used. They withstand temperature depending mechanical stress in the cycling mode. Compared to standard thermoelectric modules they withstand more cycles under same conditions.

The MTBF (Mean Time Between Failure) for thermoelectric modules of Kryotherm is 200'000 hours at ambient temperature. The life cycle of the fans is shorter and thus crucial.

5 WHERE THERMOELECTRIC COLLERS ARE USED
Thermoelectric coolers are suitable for a wide range of applications. Hereafter only a small selection of applications:
- Small cabinets
- Displays
- Control panel
- Refrigerated container

6 TEMPERATURE CONTROL
Cooling units are often built for the operation at a constant dc voltage. They can also be operated with a controller. It is to be noted that the supplies for the thermoelectric modules and the fans must be separated. Mainly controllers with PWM output (= Pulse Width Modulation) are used. They need only one semiconductor switch. The dissipation in the controller is small. If the switch is implemented as H-bridge, the direction of current can change and thus cooling and heating are possible.
Example of a controller for thermoelectric modules with PWM output:

7 SELECTION OF A SUITABLE COOLER
If a cooling unit is also used for heating, the cooling must be considered for the determination of the cooling unit. The cooling power is always smaller than the heating power (see 2.3).

For the determination of the optimal thermoelectric cooler the following values must be given:
- Tc (temperature on the cold side, in-cabin room)
- Th (temperature on hot side, ambiance)
- Qc (cooling capacity in-cabin room)

The above values often cannot be simply determined. Then one must assume values, which must be examined in experiments for their correctness.

7.1 Customized cooling units
Frequently the dimensions of standard cooling units do not fit into application. In this case a customized cooling unit is to be considered.

Deltron AG will be glad to help you with the selection of the thermoelectric coolers. Please contact us.