Peltier heat pump

1 Goal

Cooling capacity, heating capacity and capacity coefficient of Peltier heat pump are defined under various usage conditions.

2 Theory

If the current can be flowed through one available current circuit from two various materials, one material is cooled and another is heated. The reason is the different output of the energy W_A, which must be brought to free electrons in the different materials, so that they can leave the material.
In case of the transition from one material to another an energy threshold must be overcome, the transition energy. Depending on the current direction it is positive or negative. In the fig. 1 the electrons move on the cold side corresponding throw the distance n-type semiconductor→metal→p-type semiconductor. Therefore the energy ΔE_1-ΔE_2 must be used. The similar amount of energy becomes free on the heat side. The energy is transported in the heat form from cold to heat side. If the current direction changes, the direction of the heat transport turns around, cold and heat side are exchanged.

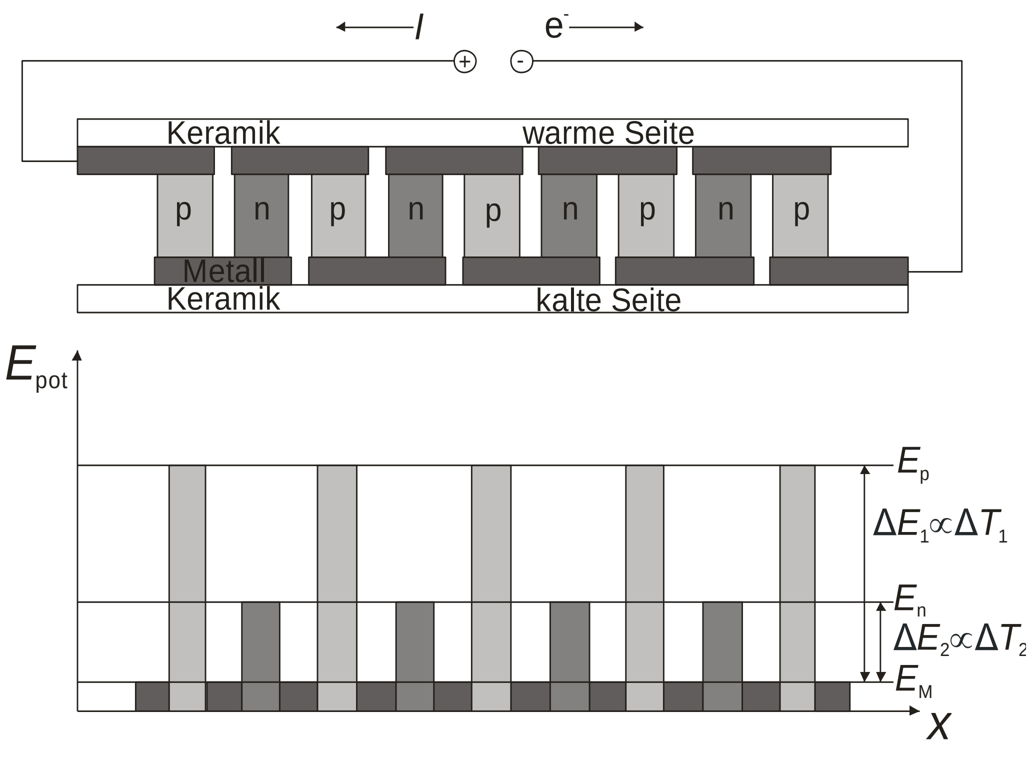


Fig. 1: A Peltier element is a serial position of contacts, which are realized by a p-metal-n- or n-metal-p-contact with two differently doped semiconductors. As a result, a sequence of the cool and heat metal positions appears, which make as usual the heat and cold side of the Peltier element.

This effect is discovered 1834 by the watchmaker Peltier and is called after him. Here is the pump capacity P_P of per time t transportable heat amount Q.
It is the current force I proportional.

$$\frac{Q}{t} = P_P = \pi \cdot I = \alpha \cdot T \cdot I \qquad (1)$$

π: Peltier coefficient,
α: Seebeck coefficient
T: absolute temperature

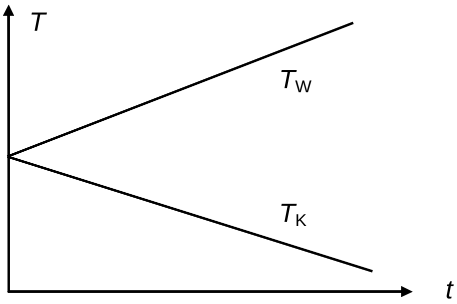


Fig. 2: Temperature variation of cold and heat side of a Peltier element by pure Peltier effect.

Therefore by pure Peltier effect the temperature difference rises between cold and heat side with constant current linearly. To take into account is certainly, that the Peltier effect always appears accompanied with other processes. These are explained in the following.

2.1 Joule heat

The current is the movement of current carriers. In this case the heat is produced, the capacity of which P_J rises with the current force I. From this heat input is touched upon the cold and heat side in equal measure.

$$P_J = U \cdot I = R \cdot I^2 \qquad (2)$$

U: voltage
R: resistance of the Peltier element

2.2 Heat capacity

As the heat and cold side stand in contact with each other, the increasing temperature difference is compensated. The capacity of the heat capacity P_L is proportional to temperature difference T_W - T_K and leads to the fact, that the temperature difference comes close to the constant value ΔT.

$$P_L = \lambda \frac{A}{d}(T_W - T_K) \qquad (3)$$

λ: heat conduction of material
A,d: surface and density of the Peltier elements

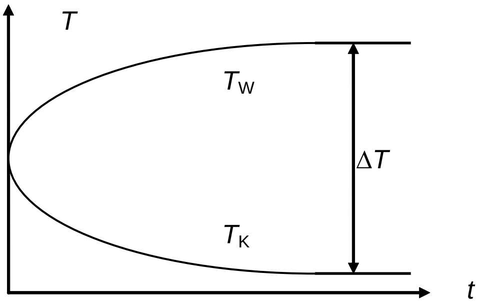


Fig. 3: Temperature variation of the Peltier element-sides, if the heat capacity is taken into consideration.

2.3 Thomson effect

If current flows in capacity with temperature fall, it can take up or give way the heat in dependence to material. The direction of the heat flow depends on the current direction, on the notation of the Thomson coefficients τ and on the direction of the temperature gradients dT/dx. It is described by

$$P_T = \tau \cdot I \cdot \frac{dT}{dx} \approx \tau \cdot I \cdot \frac{\Delta T}{d} \qquad (4)$$

P_T: production of the Thomson effect
I: current force
ΔT: temperature difference

The temperature difference remains constant.

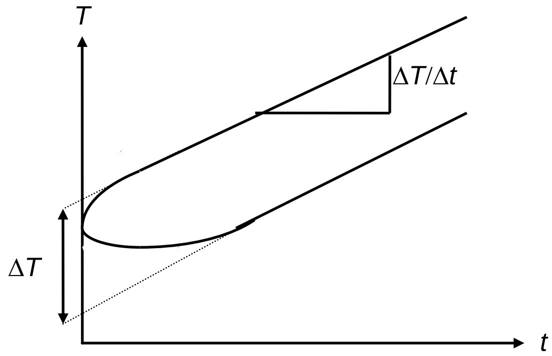


Fig. 4: Temperature variation of the sides of a Peltier element by taking into account of Joulean heat, heat capacity and Thomson effect.

3 Tasks

- From the temperature-time-function on the heat side and cold side pump capacity in heat and cold usage is defined, P_W, P_K and capacity coefficient in heat and cold usage η_W, η_K.

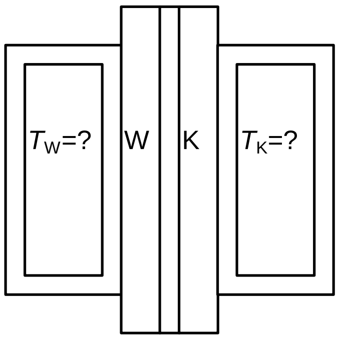
- The pump capacity in the heat usage P_w and the capacity coefficient η_W are defined at constant current force und constant temperature of the cold side.

- P_K and η_K of the cold side are defined at air-cooling of the heat side.

3.1 Realization

- The water containers are fixed on both sides of the heat pump and filled with water of identical temperature. At constant current I_P and constant voltage U_P the temperature variations are measured in both water containers as functions of the time $T_W(t)$, $T_K(t)$. The measurement widens above 20 minutes.

In estimating the temperatures T_W and T_K against the time t are brought. The increase $\Delta T_i/\Delta t$ of this variation is a measure for the heat pump capacity P_i, i=W;K. From the linear region of the curves can be calculated



$$P_i = C_{ges} \cdot \Delta T_i / \Delta t \, ,$$

also the capacity parameters

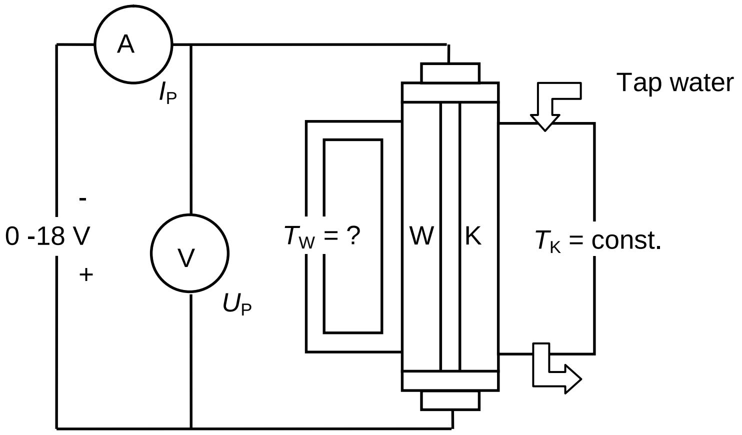
$$\eta_i = P_i / P_{el} \quad \text{with} \quad P_{el} = I_P \cdot U_P \, .$$

At that is

C_{ges}: specific thermal capacity of the general system, composed of water, brass container and copper block (C_{ges} = 1121 J/K)
ΔT_i, Δt: temperature- and time period of the raising triangle in linear region
P_{el}: electric capacity
I_P, U_P: current and voltage in Peltier element

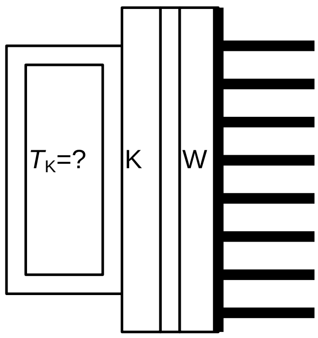
- A water container is fixed on the heat side of the Peltier element and a flowing heat exchanger is fixed on the cold side through which tap water flows. The useful current is so polarized, that the water is heated in water container.

  Analog to part 1 P_W and P_K as well as η_W and η_K are calculated from the increase of the curves $T_W(t)$ and $T_K(t)$ in linear region. The results can be discussed.



- A water container is set on the cold side of the Peltier element and a cooler is fixed on the heat side The temperature of the cold side is measured as function of the time, at that the cooler is fixed in quiet environment air. This part of experiment is done, as preceding, for 20 minutes.

  Bring $T_K(t)$ against the time and discuss the curves!



Appendix

Capacity balance

In the following different influences are considered on the temperature behaviour. So we get for the heat pump capacity on the cold side $\Delta T = T_W - T_K$:

$$-P_K = P_{P,K} \mp \frac{P_T}{2} - \frac{P_J}{2} - P_L = \alpha T_K I \mp \frac{\tau I \Delta T}{2d} - \frac{I^2 R}{2} - \frac{\lambda A \Delta T}{d}$$

or for the heat side:

$$+P_W = P_{P,W} \pm \frac{P_T}{2} + \frac{P_J}{2} - P_L = \alpha T_W I \pm \frac{\tau I \Delta T}{2d} + \frac{I^2 R}{2} - \frac{\lambda A \Delta T}{d}$$

The supplied electric capacity is

$$+P_{el} = P_P + P_J + P_T = U_P \cdot I_P$$

The capacity balance is also graphically represented: