http://dx.doi.org/10.21611/qirt.2014.142

Increasing performances on blackbodies to extend their temperature range

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Abstract

Calibrating IR sensors for thermography or imaging applications requires covering a wide temperature range from temperatures below ambient to extremely high temperature. Such a wide range cannot be covered with a single IR source. It usually requires two sources:

- A low temperature source covering temperatures around ambient temperature. Usual temperature range is from 0°C to 150°C.
- A high temperature cavity source from 100°C to 1200°C

For the first type of sources, the required electric power is much higher compared to the emitted optical power. For the second type of sources, the stabilization time is usually prohibitive at the junction temperature, i.e. below 150°C. To pass through these two inconvenients, HGH has developed two methods to improve the range of temperature of its blackbodies, to speed up the cooling/ heating time and to improve the power efficiency of the blackbodies.

1. Increasing electrical efficiency of low temperature blackbodies

Low temperature blackbodies simultaneously require cooling and heating devices to reach temperatures below and above ambient temperature. Thermoelectric elements using Peltier effect are the appropriate device allowing such function. They absorb heat from the emissive surface and reject heat through a cooling system. This justifies why low temperature blackbodies have to be cooled.

1.1. Temperature regulation principle on low temperature blackbodies

The operating principle of the emissive head of a low temperature blackbody is described as follow:

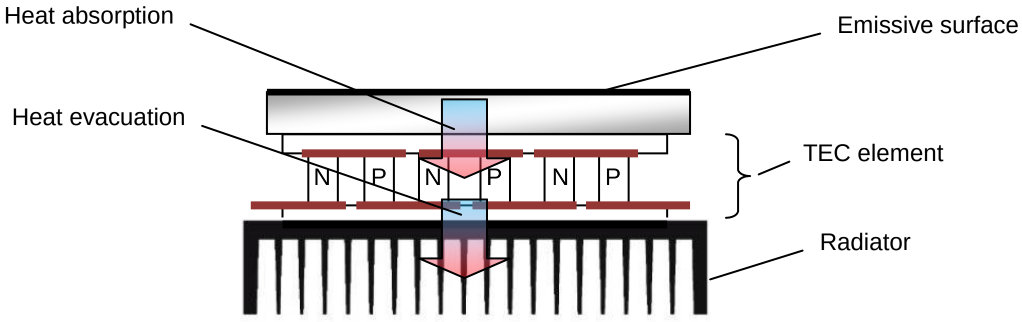

Fig. 1. *Low temperature emissive head principle*

The heat is absorbed on the emissive plate and rejected toward the radiator: the emissive surface cools down. The temperature of the emissive plate is measured in real time and this information is sent to an automatic regulation loop which continuously adjusts power to the thermoelectric element and allows fine regulation of the temperature of the emissive surface.

To heat up the emissive surface, the direction of the current changes and the heat is absorbed this time on the radiator which temperature is supposed to remain constant and rejected to the emissive surface which temperature increases. Actually this reverse thermoelectric effect is also combined with the Joule effect (i.e. the temperature of a resistance increases when it receives current). This combination of the two effects (Peltier and Joule effects) leads to a faster increasing of the temperature and a wider temperature range.

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The advantages of this configuration are the following:

- The regulation speed is particularly high: typical slew rate is 30°C/ minute either toward temperatures above or below ambient temperature.
- In addition with a high-performance servo-control, the regulation stability gets down to 2 mK. This specification is particularly necessary for testing high-performances IR cameras which NETD is lower than 20 mK.

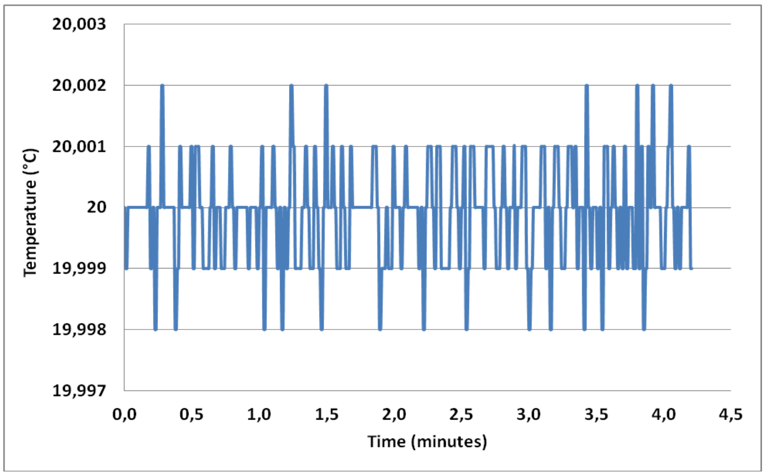

Fig. 2. *Low temperature blackbody regulation stabilty*

Since the heating combines the Joule and the Peltier effects, the maximum temperature difference between the emissive surface and the radiator is higher for positive values than for negative values. To decrease the minimum temperature of the blackbody, the efficiency of the heat evacuation through the radiator is increased by using a fluid circulating radiator. Fluid may be water or cooled fluid based on ethanol or silicon oil.

Another issue is that the thermoelectric elements require only DC power supply and, for large area blackbodies, a mosaic of thermoelectric element will require very high DC power supply and especially very high current. As an example, for a 7 inch low temperature blackbody with a temperature range from -5°C to 150°C, typical voltage and current are respectively 35V and 8A. Moreover, as this blackbody is able to both reach temperatures above and below ambient temperature, the voltage or the current has to switch from positive to negative values. In the above example the voltage range is [-35V; 35V] and the current range is [0A; 8A]. In addition, a true 0A must be reached to get the blackbody stabilized at ambient temperature i.e. when temperature difference between emissive surface and ambient temperature equals 0°C.

The overhaul principle of the power supply of the TEC elements of a low temperature blackbody is described below:

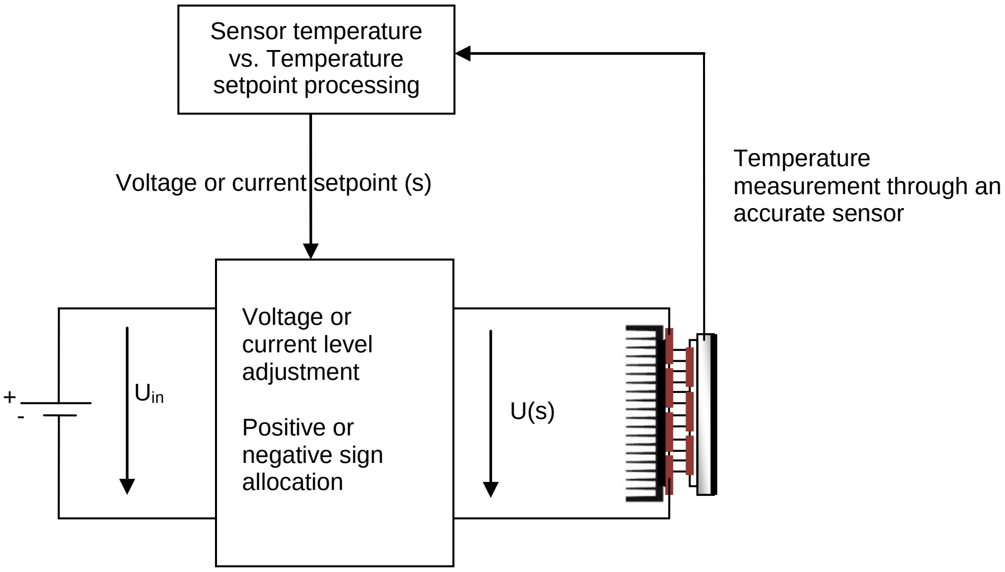

Fig. 3. *Low temperature blackbody supply principle*

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The power is generated by a DC power generator which delivers a fixed power voltage U_{in}. U_{in} is higher, in absolute, than required maximum voltage by the blackbody and this power generator is able to deliver a current which is also higher than the required maximum current.

A converting board simultaneously adjusts this voltage level and allocates a sign to this adjusted voltage according to the setpoint (s) calculated by a processing device from the comparison between the actual temperature of the blackbody and the temperature setpoint.

This adjusted and signed voltage U(s) is sent to the TEC elements of the blackbody.

The converting board specifications require:

- to accurately adjust the output level voltage according to the input setpoint,
- to be able to allocate a sign to the output voltage with the imperative condition of reaching as close as possible 0V absolute value,
- to increase power conversion efficiency to limit the input voltage of the power generator and avoid thermal dissipation.

1.2. Usual amplifying method

The usual method is to use a class A amplifier with transistor effect. The principle may be described below:

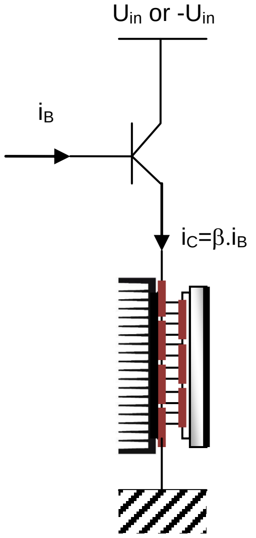

Fig. 4. *Usual amplifying circuit principle*

The law between the input current (i.e. current setpoint) i_B and the output current i_C is linear. The output current i_C is then accurately adjusted and the voltage is set according to the TEC resistance, i.e. varies with the temperature. However, the optimized operating points are when $i_B = 0$ and when i_B is maximum.

In the first case, the resistance of the transistor is high. But as the current is very small, the TEC element receives no power and the thermal dissipation is small. This operating point corresponds to a temperature regulation closed to the ambient temperature.

In the second case, the transistor has a negligible resistance compared to the TEC element, and the thermal dissipation into the transistor is also very small, whereas the TEC element receives a maximum current. This operating point corresponds to the maximum heating or cooling transitory phase of the blackbody, before stabilisation.

Between these two optimized operating points, the resistance of the transistor is equivalent to the resistance of the TEC element and the thermal power dissipated into the amplifier is equivalent to the power dissipated into the TEC element. This phase corresponds to the regulation phase, which is the most usual operating phase of the blackbody.

Typical efficiency of this class A amplifier is less than 50% and requires a DC power generator at least twice more powerful than the power required for the TEC element. This may be acceptable for small area low temperature blackbodies but cannot be used for large area blackbodies with wide temperature range.

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1.3. Power efficiency increasing

A class D amplifier is used to increase power efficiency. Though this method is regularly applied to motor regulation, we demonstrate it can be also applied to temperature regulation through TEC elements. The operating principle of this switching power supply is described hereafter:

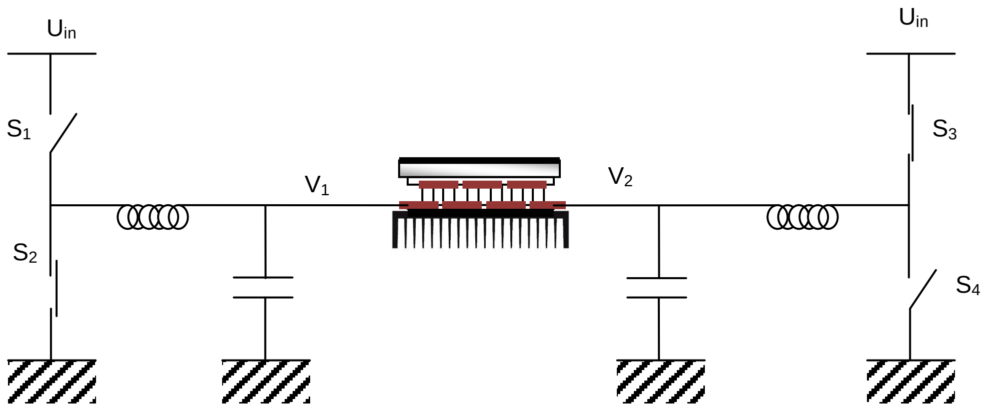

Fig. 5. *High efficiency amplifying circuit principle*

The switches S1 and S4 are simultaneously driven. Their status is always opposite to the status of the switches S2 and S3 which are also simultaneously driven. Consequently the two voltages V_1 and V_2 are:

V_1= s U_{in} and V_2= (1-s) U_{in} with 0<s<1 where s is the proportion of the opening duration of the switches.

Depending on the value of s, the voltage at the input terminals of the TEC element may be positive or negative. In case that s= 0.5, V_1=V_2 and the voltage equals a true 0V signal as required by an accurate regulation loop.

The accuracy of the output voltage level versus the power setpoint depends on the switching frequency of the input voltage and on the cut-off frequency of the low pass filter.

The thermal dissipation is limited and the typical efficiency is at least 85% which allows the use of acceptable DC power generator even for large area and wide temperature range blackbodies.

2. Improving cooling time and range on high temperature cavity source

A cavity blackbody is the appropriate IR reference source for IR sensors which require high radiance levels. It combines high emissivity independent from wavelength and high speed warm up and high stability thanks to its light trap structure. However, the inconvenient of this structure is that it leads to a prohibitive cooling time.

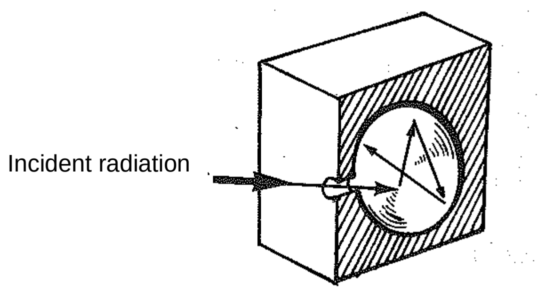

Fig. 6. *Light trap principle*

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2.1. Cavity blackbody description and features

A cavity blackbody operates as a light trap: incident rays entering though the small aperture reflects on the internal surfaces of the cavity. Since the cavity surface already has an intrinsic high emissivity (usually about 0.9), the incident radiation is partially absorbed every time it reflects on the cavity surface. Indeed, this reflection is diffuse. Finally very few incident radiation escapes from this light trap.

By comparison with primary standard IR reference sources, the emissivity of HGH's cavity blackbody is higher than 0.985 over 1 to 3 µm spectral band and higher than 0.99 above 3 µm.

This cavity is surrounded by a set of heaters, heating the cavity to very high temperatures. The temperature of the cavity is measured and controlled in real time through a thermocouple sensor. A refractory casing around the heaters limits the losses through conduction. A double surface cover allows the external cover of the source to remain at room temperature while the temperature of the cavity is 1200°C.

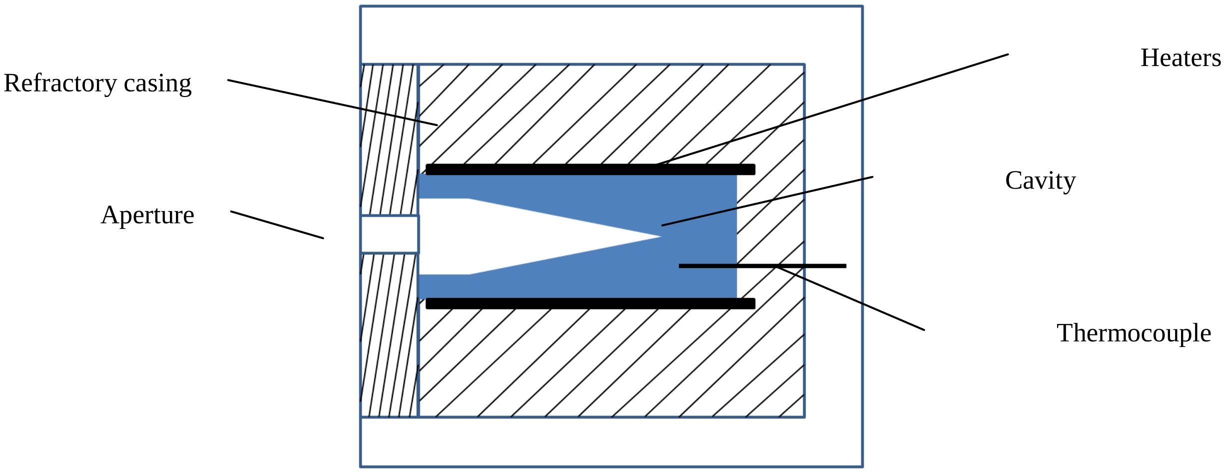

Fig. 7: *cavity blackbody structure*

In addition to a high emissivity as explain above, this configuration leads to other interesting specifications: high speed warm up and high stability, as described hereafter.

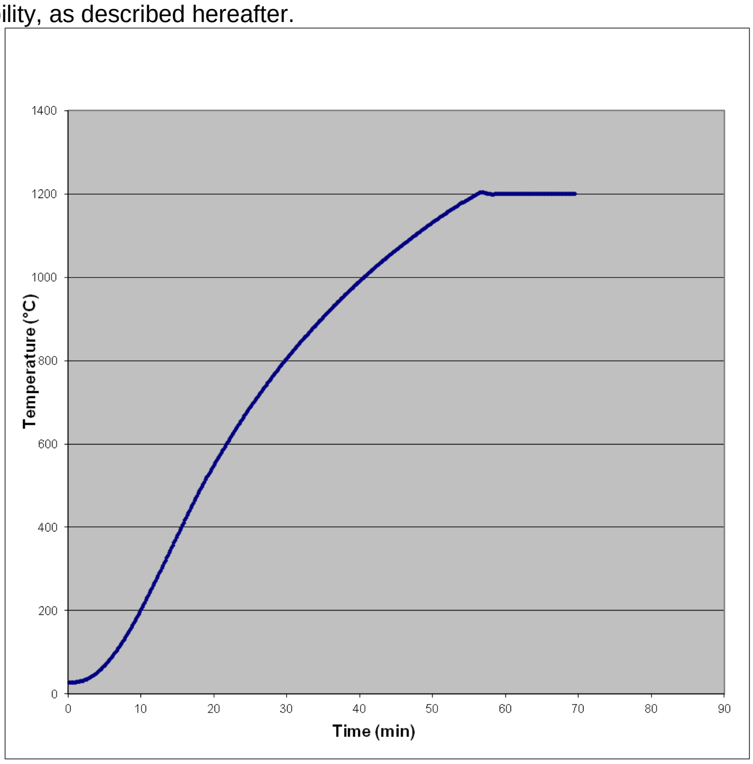

Fig. 8: *rising time from ambient temperature to 1200°C*

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Rising time from ambient temperature to 1200°C ±0.5°C is less than 1 hour.

Once the cavity has reached a temperature, the temperature remains stable over time within less than 0.1°C rms. See below example of cavity temperature during 10 minutes at 900°C.

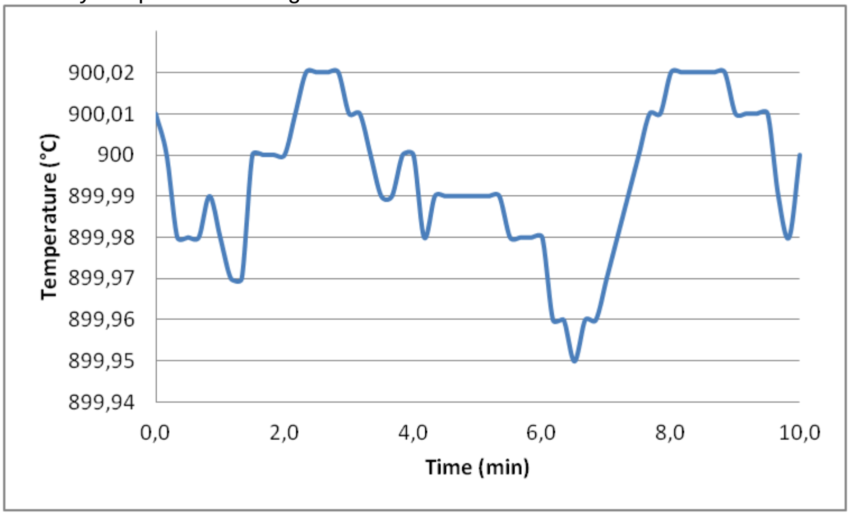

Fig. 9: *example of stability curve of the temperature over 10 minutes at 900°C*

The advantage of such a high stability is that it allows the measurement of the noise (such as NETD measurement) of high-end IR sensors to comply with the 4:1 ratio law, saying that a reference equipment should have less than ¼ of the measurement uncertainty of the tested device.

However, due to the confined configuration of this structure, the thermal losses are very small compared to the energy of the cavity at 1200°C. Since these losses depend on the temperature difference between the cavity and the ambient temperature and decrease at least as fast as the temperature of the cavity decreases, the cooling time from 1200°C down to temperature about 50°C is more than 5 hours as shown on Fig. .

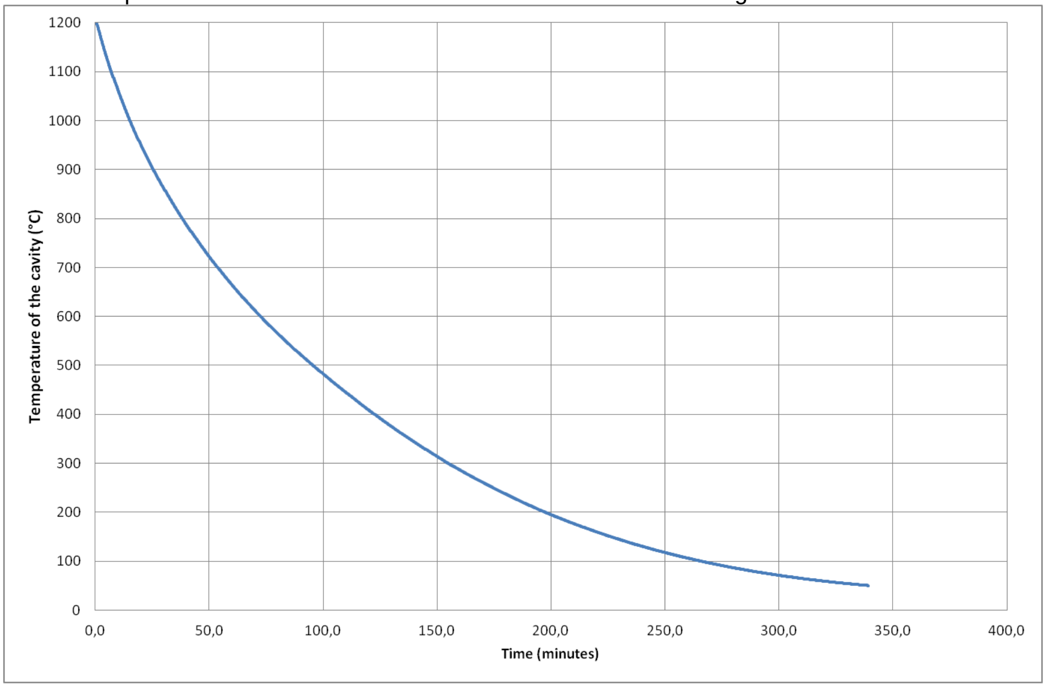

Fig. 10: *Cooling curve of a cavity blackbody from 1200°C*

Practically, because of this long cooling down time, calibration and testing procedures of IR sensors have to start from low temperatures to high temperatures. This operating constraint is no longer acceptable by blackbodies users and HGH decided to modify its cavity blackbodies to significantly decrease cooling down time.

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2.2. CoolSpeed system

The internal structure of the cavity blackbody has been improved to allow heat evacuation through convection. This modification is called CoolSpeed system. The CoolSpeed system is driven from the blackbody controller. The controller has the possibility to activate or inhibit this system.

Thermal losses through convection were previously evacuated through 2 fans located at the back face of the blackbody. This evacuating system remains unchanged with the CoolSpeed system. However during the tests, a thermocouple is located at the output of each fan to measure the temperature of the evacuated heat. To limit the temperature of the evacuated air to acceptable values, the CoolSpeed system is activated only below 700°C. Indeed, the gain on the cooling speed due to CoolSpeed system is not significant above 700°C since the "classic" thermal losses, i.e. mainly radiation losses, are high.

The temperature of the cavity is measured while cooling down in the above conditions (see Figure).

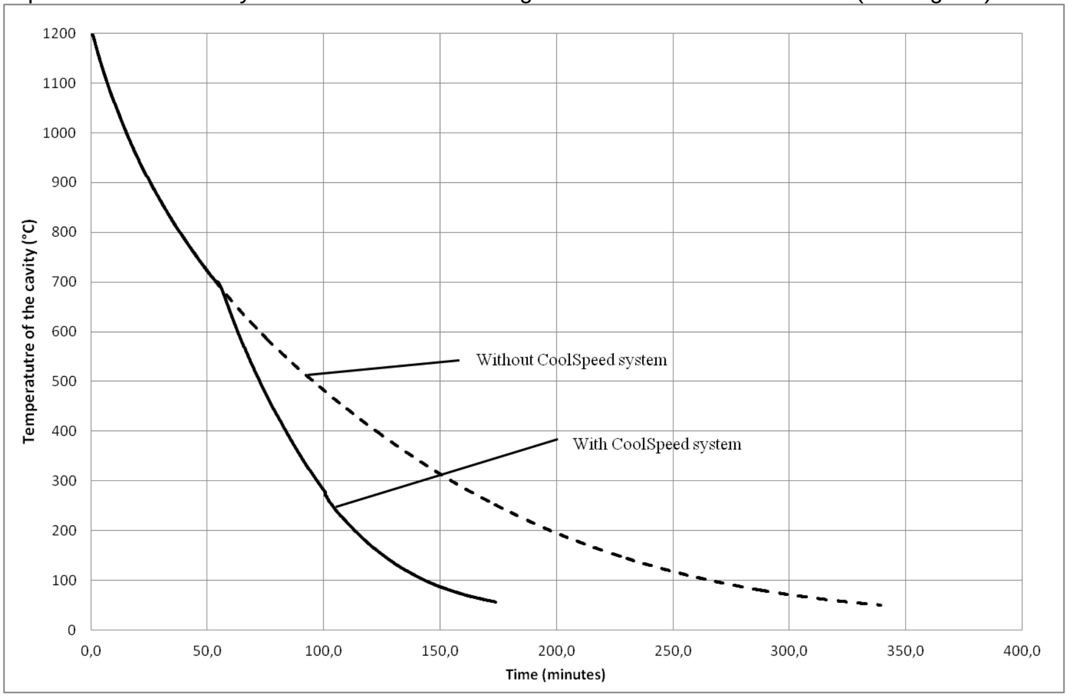

Figure 11: Cooling curve of a cavity blackbody from 1200°C without and with CoolSpeed system

In this case the maximum output temperature of the evacuated air is 50°C and the cooling down time from 1200°C to ambient temperature is about 3 hours instead of more than 5 hours (see previously Fig.). Moreover if the initial temperature is 700°C, the cooling time to ambient temperature is then divided by more than 2 compared to the cooling time without CoolSpeed over the same range.

As a practical example, the figure below shows the stabilization process from 1200°C to 300°C of a blackbody equipped with a CoolSpeed system device. Please note the CoolSpeed system starting point and stopping point. In the example below the stabilization at ±0.2°C from the temperature setpoint is 2 hours and 20 minutes.

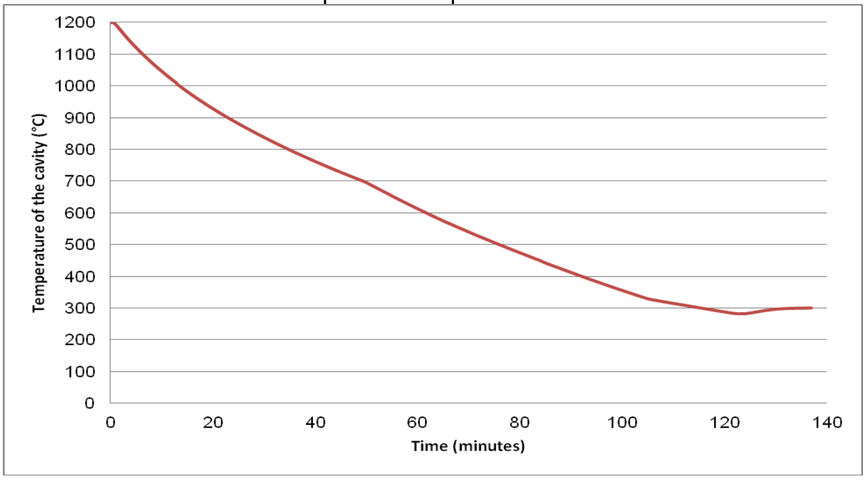

Fig. 22. *Example of cooling and stabilization process at 300°C*

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3. Conclusion

For 30 years, HGH has designed and manufactured infrared reference sources, for all applications of infrared sensor characterization. The range includes: low temperature extended area blackbodies, differential and absolute infrared reference sources, high temperature extended area blackbodies and cavity blackbodies with extended temperature range. These reference sources combine high-end features: broad temperature range, high emissivity on whole infrared spectral bands, high angular and spatial uniformity, high stability.

Based on this strong expertise, HGH commits itself to constantly improve its product lines. This paper presents two methods that HGH has developed in order to offer high performance blackbodies with extended temperature range. The first innovation significantly increases the electrical power efficiency of low temperature blackbodies, enabling to maintain the best thermal characteristics over large emissive areas and wide temperature range. The second cuts the cooling time of cavity blackbodies in half, improving the flexibility of use of high temperature reference sources. Thanks to these developments, HGH can provide all the necessary equipment to assess IR systems with the best reliability, on the widest temperature range.

REFERENCES

[1] Gaussorgues, G., [Infrared Thermography], Chapman & Hall, London, chapter 3 (1994).