globalPoint ICS

Intelligent Communication Solutions GmbH

Measurements with the PTP®

Professional Temperature Profiler

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Qualifying your Thermal Equipment

1   Introduction

With a comparison of soldering installations, the difficulty often exists to find objective evaluation criteria. This lies, to one hand, in the quite different construction details of the installations, on the other in the varying conditions during evaluation and measurement on the spot. Temperature profiles offer an objective evaluation result only superficially. Its comparability is restricted by the selection of the "right" measurement boards, by the appropriate connecting/ fixing of thermocouples and by the observance of always identical measurement procedures. It is found that, in each case, set parameters of the soldering installation admit a comparison of determined temperature profiles at all.

The measuarment-board must always reflect the situation of interest of the future installation operators or users.

The following fundamental differences should be highlighted here:

The soldering installation is used **only for the production of one single product**. In this case, it is advisable to use a measurement board, which preferably reflects the real relations (heat transfer, heat-management etc.) of the board to be soldered. For this, the different measurement standards, that are installed on the PTP®, are especially useful. However, if the reflow soldering installation is flexibly used, that means **different products are manufactured,** the measurement board must reflect a cross-section of the thermal and gravimetric relations of the boards to be soldered. When the user has the task, to compare different soldering installations of different construction and of different suppliers from each other, the measurement board should be able to grasp the power and tolerance limits of the soldering installations. A multitude of thermocouples usefully arranged on the PTP® supports this intent. The manufacturers of electronic boards and components stand more and more in the duty to prove the machine and process capability. On the topic of "planning production installations", the **DIN ISO Norm 9002** demands the proof that soldering installations work under controllable conditions. To prove this, tests of the process capability are to be enforced. Measurements with the PTP® represent spot checks of process capability tests.

The application-areas of the PTP®

- The comparison of soldering installations

- Measurement of power - and tolerance-limits of soldering installations

- Assessment of the efficiency of the heat-transfer

- Assessment of the thermal separation of heating zones

- Measurement of the cross profile of ovens

- Assessment of the influence of heat radiation

- Temperature measurement in the installation atmosphere

- Measurement of soldering or curing profiles

- Setting and supervision of temperature profiles

- Simulation of the thermal circumstances of real electronic boards

- Supervision of the thermal parameters of soldering installations

2   Thermocouples

2.1   Principle of operation

With all soft soldering methods (reflow soldering, wave soldering, selective soldering etc) the transmission of heat to the solder and solder material is essential. The heat flow can be described here through the simplified relation **[01] :**

$\dot{q} = \alpha \cdot \Delta T$		heat flow density [W/m²]
	α	heat transfer coefficient [W/m²K]
	ΔT	temperature difference [K]

Under the assumption that for an existing soldering system and the board (soldering material) to be processed, the heat transfer coefficient is approximately constant, the heat flow density depends, above all, on the temperature difference. Therefore, temperature measurements are imperative in soft soldering procedures.

The measurement of the temperature is possible through different operational principles:

operational principles	example
radiation of a body	pyrometer
changes of the qualities of a semiconductor	IC / Chip
changes of the resistance of a ceramics	thermistoren
changes of the resistance of one piece of metal	Pt 100
Seebeck effect	thermocouples

At present, the most popular measurement method used in board production are the thermocouples. A physical phenomenon forms the basis of the electric temperature measurement through thermocouple: it is a circuit of two different metals and when the contact point of the metals is exposed to different temperatures, a voltage appears. This effect was discovered in 1821 by Thomas Seebeck and was named after him. According to the Seebeck effect, an equal electromotive force (EMF) is seated in the contact point of two metals or alloys (A and B) with different electron exit potentials. Used as wire-combinations (thermocouples) for example out of copper/constantan for temperatures of –250 to 500°C, platinum/platin-rhodium for temperatures up to 1600 °C, tungsten/tungsten-molybdenum for temperatures up to 3300 °C and nickel/nickel-chrome (Ni/NiCr) for temperatures up to 1200 °CS. The wire-ends are soldered or weld together and exposed to the measurement temperature TM. Thermo-EMFs develop at the measured point, as well as at the junctions exposed to the environment temperature TU **[02].**

A thermo voltage with the size approximately proportional to the absolute temperature T of the measured point TM can be achieved through the following measuring arrangement **(figure 2-1)** with 0°C reference. A and B symbolize the two metals of the thermocouple.
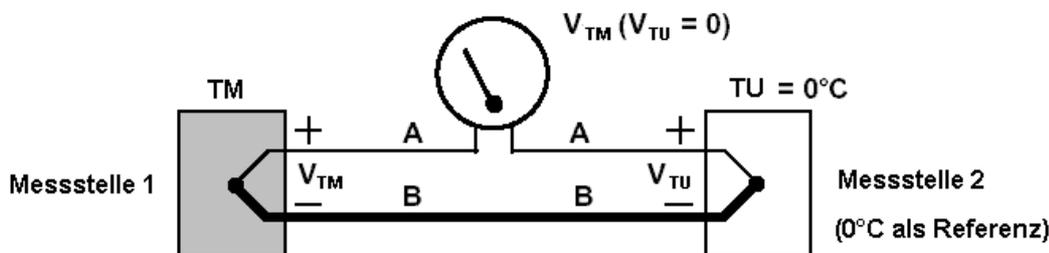

Figure 2-1: operation principle (with 0°C reference normal / ice-water)

In practice it is often found that no 0°C references are available, but it has to be assumed from variable environment temperatures TU.
With the temperature measuring data logger used in the soft soldering field, the compensation of the influence

of the environment temperature TU by feeding a correction voltage is de facto always realised. This compensation voltage Vkomp is provided through particular electric integrated circuits (IC's) and fed contrary to polarity. Figure 2-2 shows the corresponding operational principle.
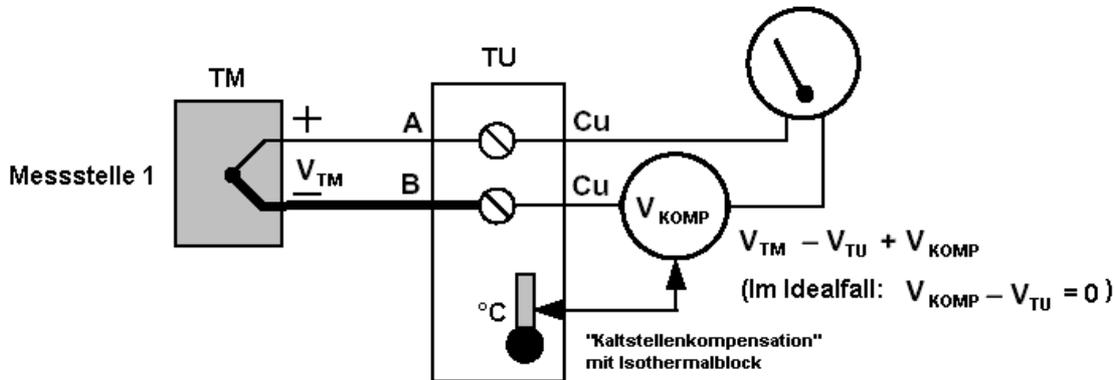

Figure 2-2: operation principle (with error compensation)

In the DIN IEC 584 **[03]** different material combinations are described. For example, the thermocouple in type K is formed from a nickel and a chromium-nickel wire (Ni/CrNi).
The selection of a thermocouple depends on the demanded temperature area, the linearity in a certain temperature area, the availability in a certain design and the price.
For measurements in the soft soldering field, Ni/CrNi thermocouples have spread world- wide, as they distinguish themselves through a convenient relationship of measurement data tolerance and price. Ni/CrNi thermocouples have an approximately linear voltage shape in the temperature area necessary for soldering (until 400°C) **(see table 2-1).**

T[°C]	0	10	50	100	150	200	250	300	350	400
U_{Th}[mV]	0	0,397	2,022	4,095	6,137	8,137	10,151	12,207	14,292	16,395

Table 2-1: voltage values for Ni/NiCr thermocouples, according to DIN IEC 584

Since there is a big number of different implementation designs with the thermocouples, some recommendations are given in the following for the selection of the right thermocouple: the mass of the thermocouple (crucial here is the mass of the measuring tip) should be essentially smaller than the mass of the measured object or point. Also it is crucial that the diameter of the measuring tip is smaller than the dimensions at the measured point (for example gullwing of a component). Coated thermocouples are to be preferred other implementation designs because of their more favourable relations of dimension and connection. However, coated thermocouples are usually also more expensive **(see figure 2-3).**
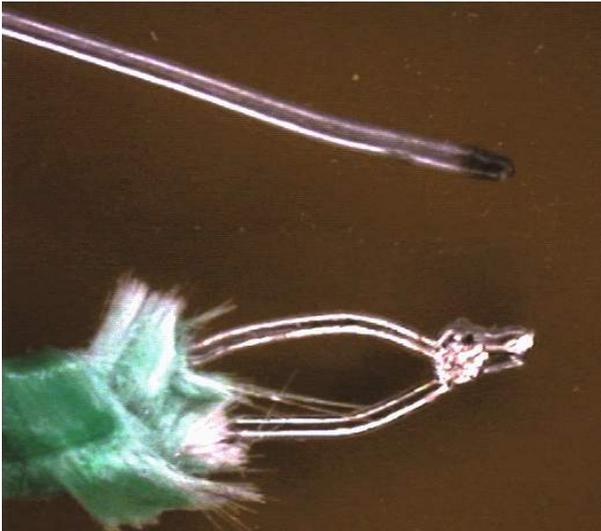
Figure 2-3: implementation designs, coated thermocouple (above),
thermocouple in fibreglass-isolation (below)

With the coated thermocouples of the type K, the coat consists of noble-steel (often Inconel 600 ^{TM} – until 1100°C useable, with good corrosion and oxidation resistance as well as excellent malleability) and the inner isolation of a ceramic powder (MgO). For the unadulterated transfer of the thermocouple voltages, it is important that in the entire chain, beginning with the measuring tip, on to the data logger, only thermocouple material is being used. This applies to the extension cables, as well as to the connection and transfer points. Since the wires consist of another metal (usually copper), two additional thermo-EMFs develop at the connections of the thermocouple metals A and B to the measuring arrangement (voltmeter/ electronic). Since the EMF-voltages developing at the joints (A/Cu and B/Cu) produce tensions within the circuit directed contrary to each other, no measurement errors result as long as both joints have the same temperature. This demand is being catered for in the construction of the PTP® by an isothermal-block.

The safest method for the connection is therefore thermocouple plug connections familiar in the trade, which are made with contacts from the original thermocouple material, through which an absolute

error of the measurement voltage is prevented. The plug material should always be selected according to the conditions of use (i.e. maximum reflow oven temperature). Commercial versions are available up to 220°C (normal implementation), 320°C (high temperature) and 420°C (super high temperature).

2.2 Ageing of thermocouples

The limit tolerances of the thermocouples are declared in the DIN EN 584 (German and European standard) and in the IEC 584 (international standard) for the type K in the best class 1 in the temperature area –40°C to +375°C as ±1.5°C. That means that with the use of thermocouples of this class, provided that no more measures (selection as well as error correction) are carried out, the measurement tolerance is +1.5°C or –1.5°C maximum. With this the tolerance of the measurement system, to which the respective thermocouple is connected, is in general not yet considered. Smaller tolerances can be achieved only through complicated calibration procedures. Here is to be considered that self produced measurement boards, which are usually manufactured using real boards, at which thermocouples are fixed are not capable to calibrate. Therefore the application of the calibration capable measurement board and measurement system, the Professional Temperature Profiler (PTP®) of the global Point ICS Ltd., is absolutely recommended.

The limit tolerances in the tables of the DIN EN 584 as well as the IEC 585 always describe the delivery state of a thermocouple. However, thermocouples are subject to an ageing process that can lead to a drift of the thermo voltage. An exact prognosis of the aging process and lifespan of a thermocouple is unfortunately not possible, since the applications dictating this are crucial:

- **application temperature**
- **mechanical change stress**
- **operation atmosphere**
- **temperature change stress**

For example in [05], a drift of approximately 1K after 10^4 hours at an operating temperature of 649°C is stated for a K type thermocouple. However, for soft soldering, these values are not applicable as there are much lower operating temperatures (≤300°C) prevailing. In order to determinate the drift of thermocouples under soft soldering conditions, [06] examined a large number of thermocouples that were in use on average 6.5 years in reflow ovens in different production environments. Figure 2-4 shows the profile of the thermo-voltage in the area of the reference temperature from 120 to 220°C.
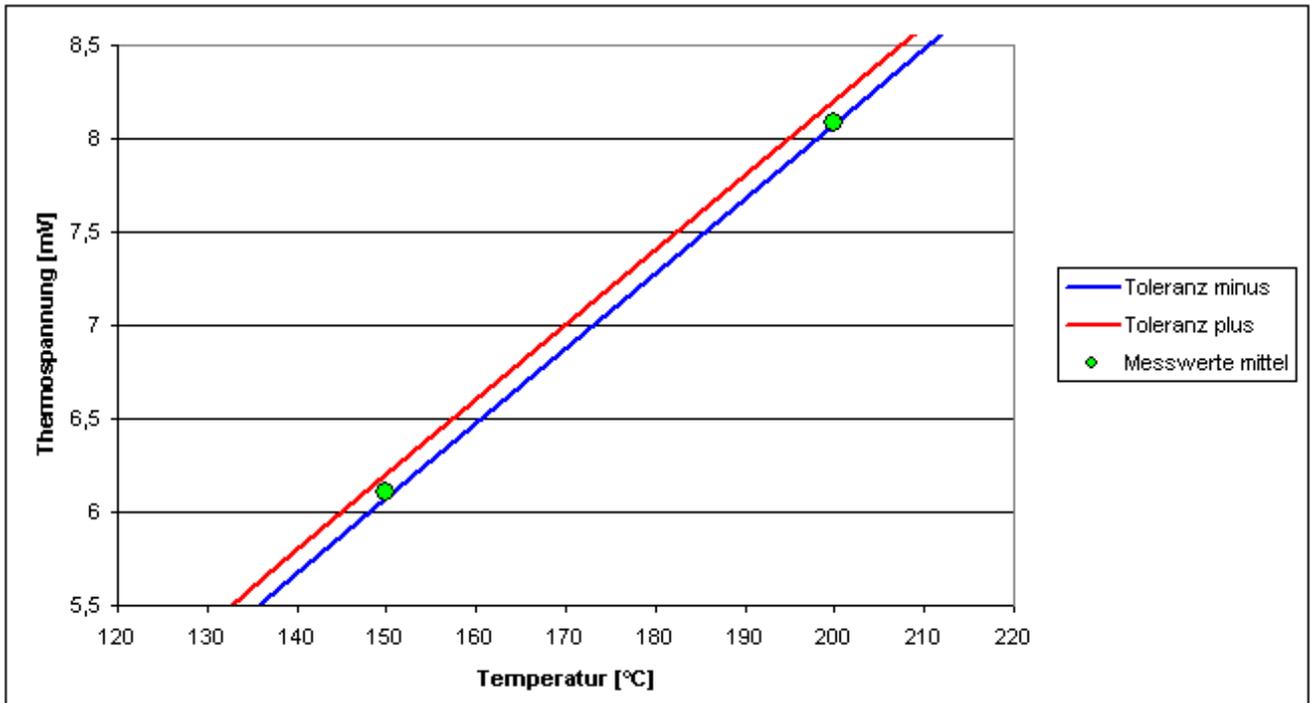

Figure 2-4: drift behaviour of thermocouples after use in the reflow oven

Over the reflow soldering temperature area of importance, from 0 to 300°C, the drift lies within the allowable limit tolerances for K type thermocouples according to the DIN IEC 584.

2.3   Attachment of thermocouples at the measured pont

An example shows that the preparation of a measurement board is not trivial. According to **[07],** temperature-differences of 24.5K have been measured between the same measurement boards, which have been produced by different participants of a soldering seminar.
With the connection of the thermocouples at the measured point (at the board) the principle of the "manufacture of a lasting connection with an excellent thermal conductivity, with simultaneously safe mechanical attachment "is required. For this, again several possibilities present themselves:

- **Simple mechanical clamping**
- **Soldering or welding**
- **Sticking**

With good implementation, the same measurement results are achieved with all types of attachment.

Figure 2-5 shows the attachment of a thermocouple using adhesive tape. For this, tapes made from Kapton, aluminium, conductive flex and fibreglass tissue are available. The thermocouple should always be mechanically unburdened in order to secure the connection.
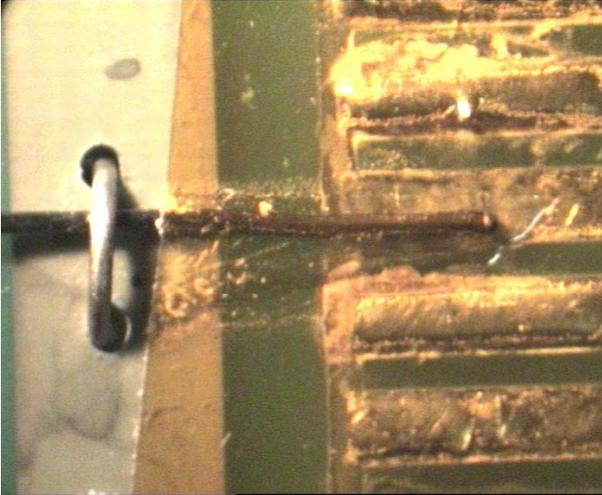
Figure 2-5: attachment of a thermocouple using a Kapton tape

The disadvantage with the cost-effective and quickly realizable attachment using a tape lies in the relatively big surface-demand on the board and the low long-term stability. Often, the connections are already useless after a few reflow rotations. For a lasting connection with a higher number of cycles, high temperature soldering **(figure 2-6)** is recommended.

However in practice, this type of connection has its own problems:

- The used solder is usually a highly leaded solder (Pb90Sn) and badly workable.
- The noble steel coat of the thermocouple is little prone to wetting.
- The module is usually irreparably damaged.
- At the measured point, the thermal mass is increased about the amount of solder.
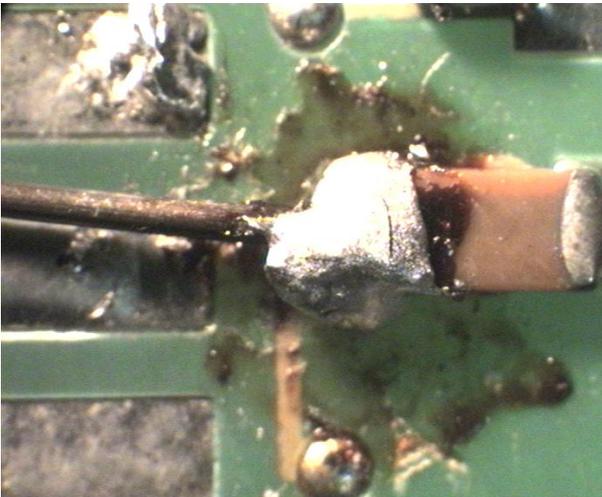

Figure 2-6: attachment of a thermocouple using a high temperature solder

In the everyday-practice of a board production, the most recommendable method is the connection using temperature resistant glue. Such glues are available in almost each board production, since they are required for the mounting of SMD. When sticking at the measured point, a very good mechanical connection must be made first between the thermocouple and the measured point (a component for example), before the glue is applied. Essentially, in order not to change the mass-proportions at the measured point, only so much glue must be used as absolutely necessary for the attachment **(see figure 2-7).**

Figure 2-7: mounting of an uncoated thermocouple using SMD glue

Through experiments we know that systematic measurement errors of several Kelvins are not eliminated if the preparation of the measurement boards is not optimal. On one hand, the atmosphere surrounding the thermo-couple wire can (even some millimetres away from the measuring tip) falsify the temperature at the measuring tip. On the other hand, measurement errors are inevitable, if the thermal coupling between measuring tip and measurement material (board) is not ideal, regarding a small thermal resistance.

The binding of the thermocouples is ideally solved on the PTP-measurement board. **Thermo figure 2-8** shows that the measuring tips of the thermocouples have assumed the temperature of the measured point over some millimetres.
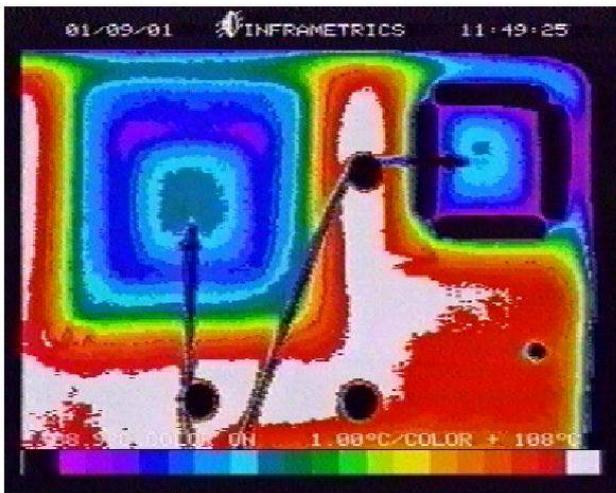

Figure 2-8: thermo figure [08] of two measured points on the PTP®

3 Methods of heat transfer

3.1 Heat transfer

The term of reflow soldering is applied to the melting of a solder source (usually in form of solder paste, see figure 3-1), which is fixed on the conductor plate. For this, the heat energy (Q) necessary is generated in a re-flow oven and is transferred onto the PCB.

$Q = c \, m \, (T_1 - T_2)$		
	c	specific heat
	m	mass
	$(T_1 - T_2)$	temperature difference

Figure 3-1: Solder paste

The physics knows the following fundamental types of the spreading of heat that find total consideration in various designs for reflow ovens: convection, heat conduction, condensation and heat-radiation.
By heat transition, the transfer of heat is understood at the point of contact of bodies of different temperatures. Liquids, gases and solids release or receive heat at the point of contact among each other if a temperature difference exists between them. The **transmitting heat Q** is a function of the **time t**, the **contacting surface A**, the **temperature difference (T1–T2)** and the **heat transfer coefficient α** that essentially represents the material qualities.

$$Q = \alpha \, A \, t \, (T_1 - T_2)$$

The larger the **heat transfer coefficient α**, the more heat can be transferred per unit of time.
Table 3-1 compares the heat transfer coefficients, as they can be present with different soldering methods.

Heat transfer coefficient: α [Wm^{-2}K^{-1}]		
radiation	20 - 30 60	preheating peak
convection	5 10 - 20 40 - 60	air in rest at 5 m/s at 5 - 20 m/s
condensation	100 - 400	
contact (liquid solder)	4000	

Table 3-1: heat transfer coefficients according to [10]

From this it becomes obvious that the wave soldering and the manual soldering are the most effective procedures for the transfer of solder heat. The condensation reflow soldering (also called vapour phase soldering) achieves the far best values with the transfer of reflow heat.

3.2 Condensation, vapour phase soldering

During vapour phase soldering, the heat set free with the phase alteration of the inert medium increases the temperature of the board to be soldered. The temperature always stays constant within the phase-alteration (latent heat), and therefore the maximum temperature of the board to be soldered is limited by the boiling temperature of the medium.

During the condensation of a vapour the heat transfer coefficients lie between 100 and 400 Wm^{-2} K^{-1}, around a factor of 10 higher than the values that are reached through radiation or convection. The vapour reaches the whole surface of the board, resulting in smallest Δ**T** at very short dwell times of the board in the condensing vapour.

For phase alterations within the condensation (vapour condenses to liquid) or vaporisation, the dimensionless Prandtl number of the liquid phase is defined [09] as:

$$ \mathrm{Pr} = \frac{\nu \rho c_p}{\lambda} $$

With the kinematic viscosity ν, the density p, the specific heat c_p and the thermal conductivity λ, it essentially contains material qualities of the medium.

Within the vapour phase soldering, a tumultuous film condensation can be assumed for the heat transfer, which can be described with the following [01] relationship between α and λ:

$$ \alpha \sim \mathrm{Pr}^{0,4} \, k $$

Especially for very heavy boards, the vapour phase soldering is often the only alternative for an economic soldering of the solder points.
Although the vapour phase soldering is older and more effective than reflow soldering regarding the heat balance, two reasons above all limit the widespread use so far:

- The high heat transfer coefficients can lead to very steep heating gradients as to be seen on **figure 3-2**. Particular preheating technologies, which have been available on the market for a few years, can provide a remedy here.
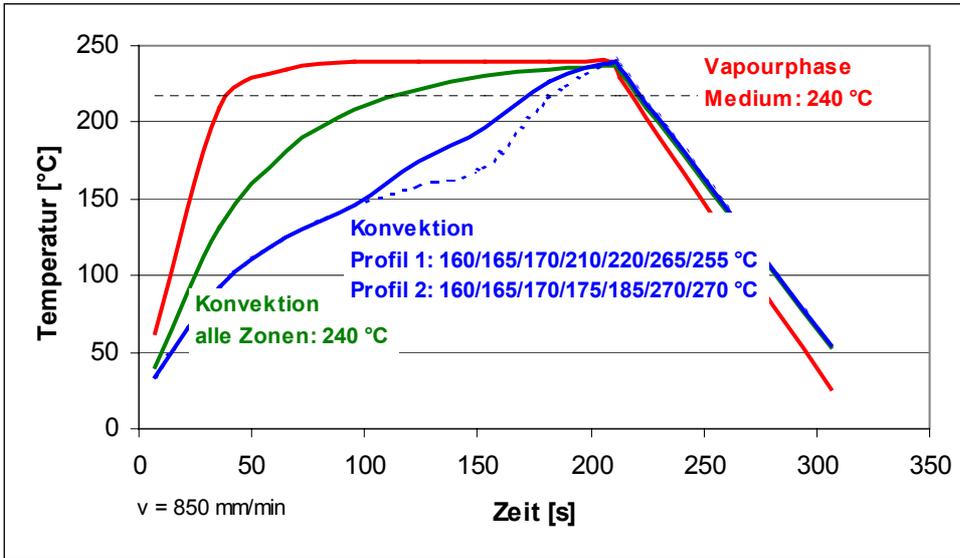

Figure 3-2: Reflow profile of a condensation soldering installation versus convection soldering

- Vapour phase soldering installations work with synthetic inert liquid media (perfluorpolyether). Although these media mean no dangerous materials nowadays, many board producers are concerned with the contact with an additional chemical material in their production plants.

3.3   Convection

The term "convection" is understood as the carriage of heat by flowing liquids or gases. If liquids or gases are warmed up, their density decreases and currents, circulation and convection are evoked by the developing buoyancy. The heat energy doesn't flow, but the medium which carries the energy. Convection is therefore always bound to a medium. The convection can be forced from outside, as this happens in convection reflow ovens through ventilators, turbines or nozzles.

In forced convection systems, the heat transfer increases with the airflow velocity of the gas (air or nitrogen).

Heat transfer coefficient α [$Wm^{-2}K^{-1}$]	
air at rest	5
air in motion at 5 m/s	10 - 20
air in motion at 20 m/s	40 - 60

Table 3-2: Heat transfer coefficients according to [10]

Figure 3-3 shows that the reached end temperature of the board increases with a higher gas velocity with constant temperature of the flowing air in the peak zone of a convection oven.
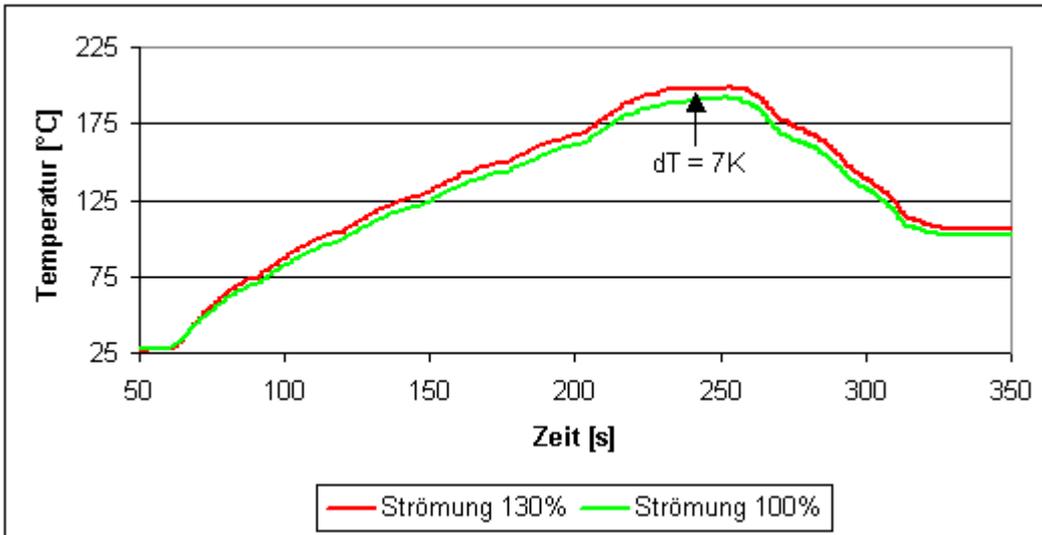
Figure 3-3: reached end temperature with varied airflow velocity

However, the maximum airflow velocity is restricted to prevent blowing single components out of the board. Convection installations have the biggest market share at the moment.

3.4 Heat conduction

The spread of heat energy within a body is called heat conduction. The heat conducting capacity **(see table 3-3)** is a material property. Metals are known to be good heat conductors while plastics and gases (e.g. air) conduct badly. If one looks at the conditions on a PCB, we find both very good heat conductors, like the copper conduction lines, and very bad heat conductors, like FR4 PCB material densely side by side.

material	specific heat conducting capacity [W/mK]
FR4-Basismaterial	0,6 - 0,9
Glas	0,3 - 2,1
Kupfer	372

Table 3-3: heat conducting capacity according to [11]

The **heat flow Q_{12}** from **volume V_1** to **volume V_2** is calculated by:

$$Q_{Leit.12} = A_{12} \frac{\lambda_1 \lambda_2}{d_1 \lambda_2 d_2 \lambda_1} (T_1 - T_2)$$

$A_{1,2}$	common surface
$d_{1,2}$	characteristic thickness
$\lambda_{1,2}$	heat conductivity

The heat transported through conduction is an essential term within the total heat balance inside a reflow board and should not be neglected.
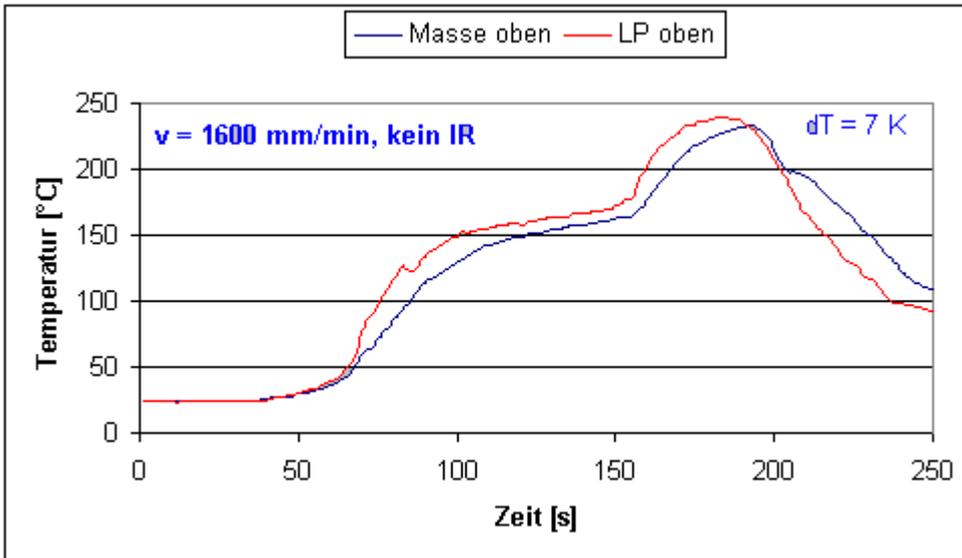
Figure 3-4: the influence of heat conduction

Figure 3-4 shows the temperature profile of two densely neighbouring measured points on the same PCB: directly on the "bare" FR4-material (red, LP above) and on a copper-surface (blue, mass above). Since FR4 has a poor heat conduction compared to copper, no complete temperature balance between the measured points takes place during the oven cycle.

3.5   Heat radiation

By the term "heat radiation", the radiation of heat energy through empty space is understood. In contrast to the already explained types of heat transfer, the radiation of heat is not bound to a medium, it is subject to the laws of electromagnetism. When radiation meets a body it is more or less absorbed by it and contributes to the increase of its temperature. The amount of **energy QStr** a body is able to absorb is dependent on the **radiation energy E**, that hits on it, the receiving **surface A** and the **absorption coefficient** α_{Str}, that describes the material-quality of the body.

$$Q_{Str} = A \; \alpha_{Str} \; E$$

absorption coefficient α	
copper	0,02 - 0,1
FR4	0,9 - 0,95

Table 3-4: absorption coefficients according to [11]

The electromagnetic spectrum of heat radiation stretches from the short wavelengths of ultraviolet radiation (100 nm until 1 µm) up to the long-wave infrared radiation (1 µms until 1 mm). While according to **[12]** the absorption coefficient of a tin-lead alloy decreases with rising wavelength, it increases considerably with insulators like the package or the PCB **(see figure 3-4).**
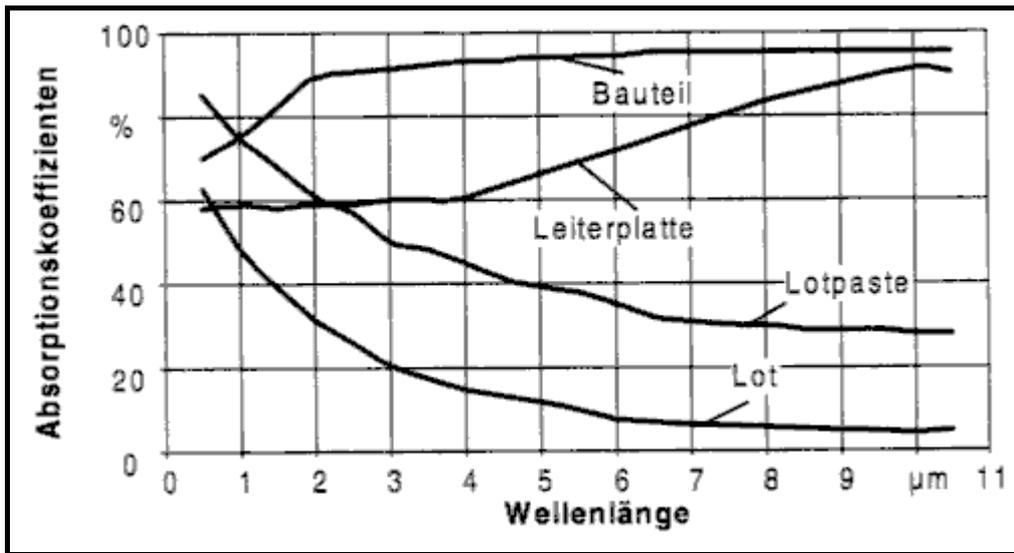
Figure 3-5:   Absorption coefficient, source: [12]

The energy of the absorbed part of the radiation is completely transformed into heat. The principle of radiation of heat is realised constructively in the infrared ovens and laser installations.

Since radiation travels rectilinearly, shadow areas due to the topography of the reflow board (different heights of the components) can be caused. Additionally, differing degrees of emissions and absorption of the single components on the board lead to an uneven warming of the board. The result is often a big ∆T between the small and bigger components on the board. This has led to a global replacement of radiation ovens in favour of convection ovens.

In convection ovens, one must always take into account that besides the forced convection, the natural radiation of the walls of the oven interior contributes a significant energy share for the warming of the board. Figure 3-6 shows the comparison of the heating profiles of two identical bodies in the convection oven, that differ only through their absorbent black and reflective bare surfaces.
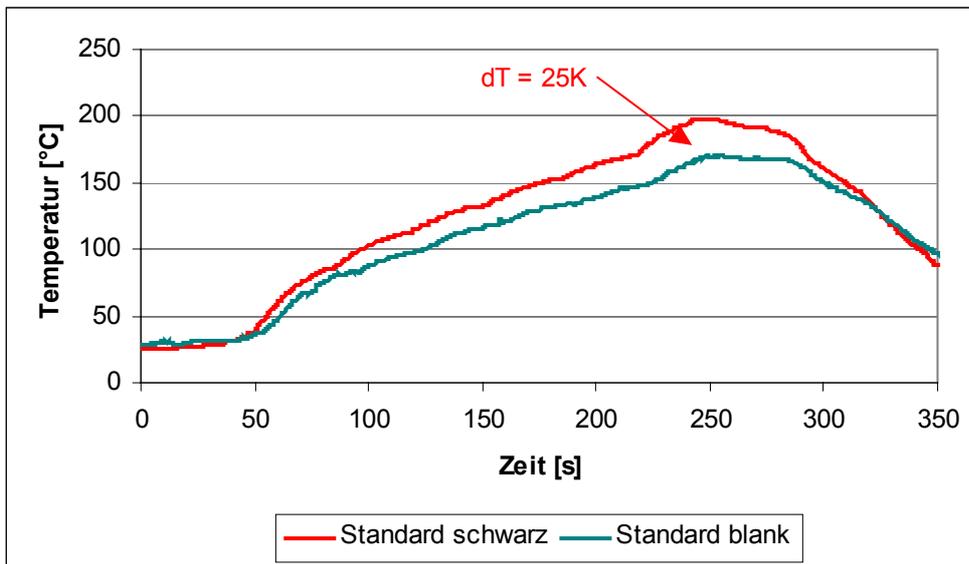

Figure 3-6: the influence of natural radiation of heat

3.6 The heat balance

Figure 3-7 shows the terms of supplied and emitted quantities of heat that contribute to the heat balance of a solder joint.
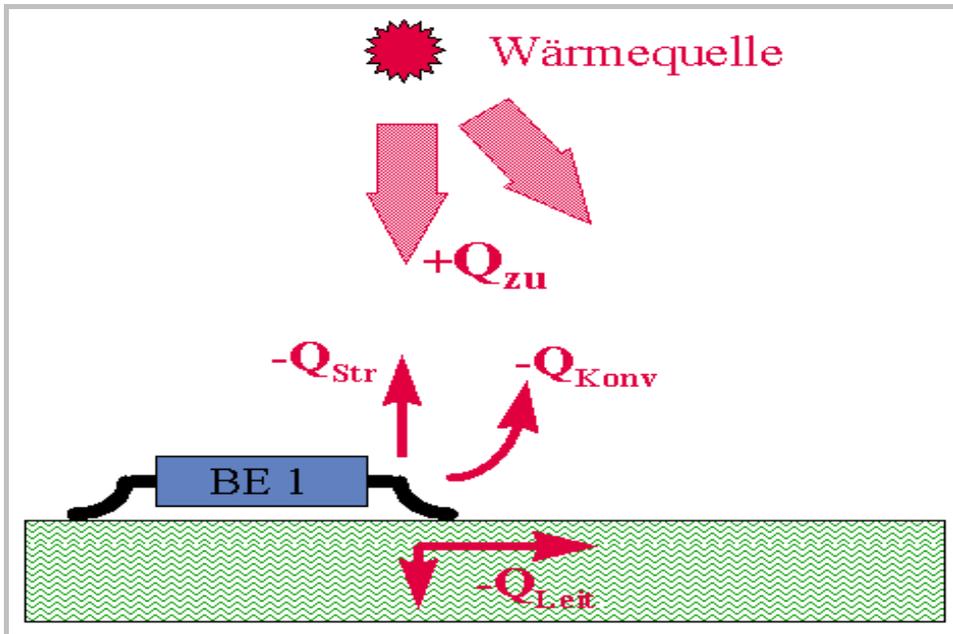

Figure 3-7: heat-balance of a solder joint

The **heat Q_{needed}** required at a solder joint consists of:

$$Q_{needed} = Q_{sup} - Q_{rad} - Q_{conv} - Q_{cond}$$

Q_{sup}	**supplied heat**
Q_{rad}	**heat carried away through radiation**
Q_{conv}	**heat carried away through convection**
Q_{cond}	**heat carried away through heat conduction**

From this it is obvious that the supplied **heat quantity Q_{sup}** must always be somewhat larger than the **heat quantity Q_{needed}**, which would be directly necessary for the liquefaction at a solder joint.

Through heat conduction, a considerable part of the heat flow at the solder joint is being lost within the PCB. This becomes especially clear when multi-layers with a high copper content are going to be soldered manually using an iron.

A second quantity of heat gets lost through natural heat radiation, which is emitted by the solder joint into the surrounding environment.

A third quantity of heat gets lost through natural convection on one hand and through the forced convection often used in reflow ovens on the other hand.

4 Reflow soldering

4.1 Cross profiles

Most reflow ovens have got width-adjustable transportation systems (for example between 50 to 508mm) and heating zones, which are reaching over the maximum width of the installation. If the construction of the heating zones creates a temperature difference over the oven width, this of course also occurs on the board to be soldered (see figure 4-1).
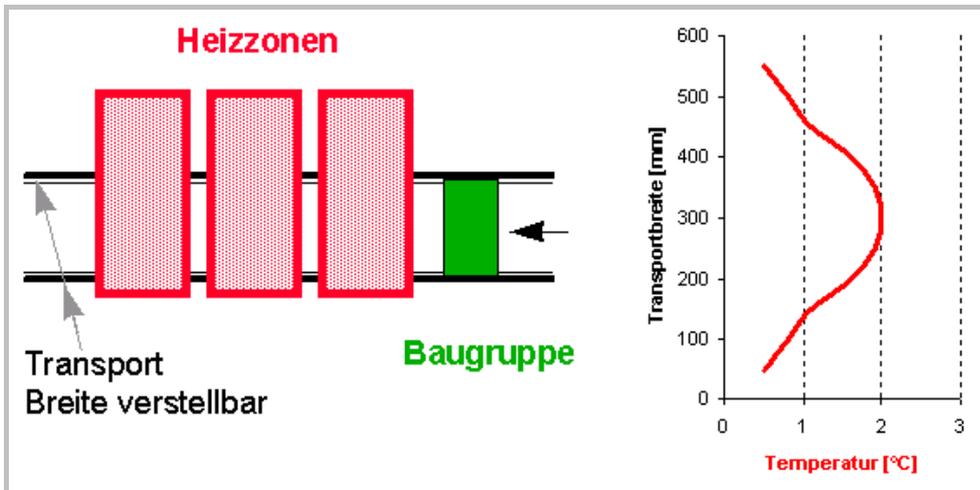

Figure 4-1: cross profile

The temperature control and the construction of almost all reflow installations available on the market don't allow the compensation of temperature differences over the width of the heating zones. Therefore, the user must have expert knowledge to predict the maximum temperature differences over the width of his reflow ovens. In other words, he must know the cross profile.

The measurement of the cross profile is done with help of an equidistant pattern of thermocouples on the PTP® (Th. 1 to 3). These thermocouples are fixed directly on the surface of the measurement boards. The material of the PTP® has poor conduction of heat at the attachment location of the thermocouples. Therefore, the influence of heat conduction of the measurement board material can be largely neglected.
Figure 4-2 shows the excellent cross profile of a nitrogen convection oven, which shows only a deviation of 1K.
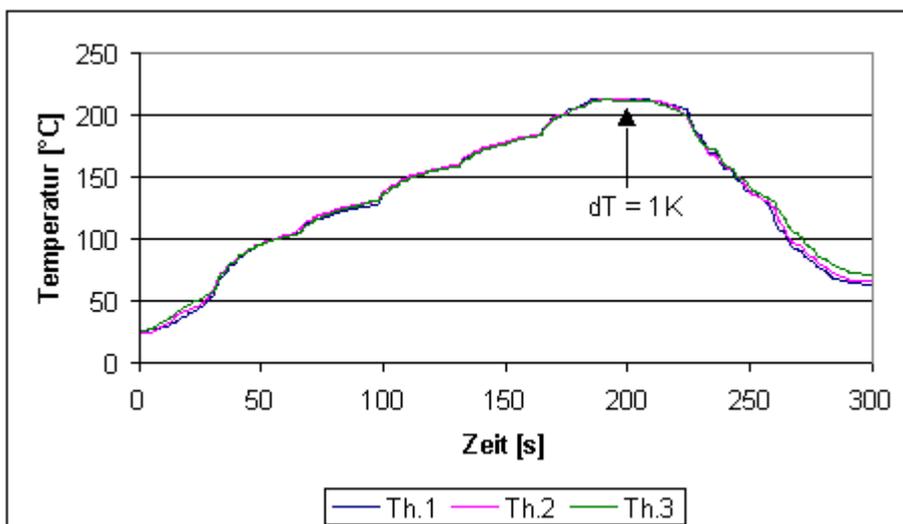

Figure 4-2: cross profile of N2 convection oven

Good reflow ovens should reach cross profiles of 3K (figure 4-3), to fulfil the requirements of the very narrow process windows in the unleaded soldering process.
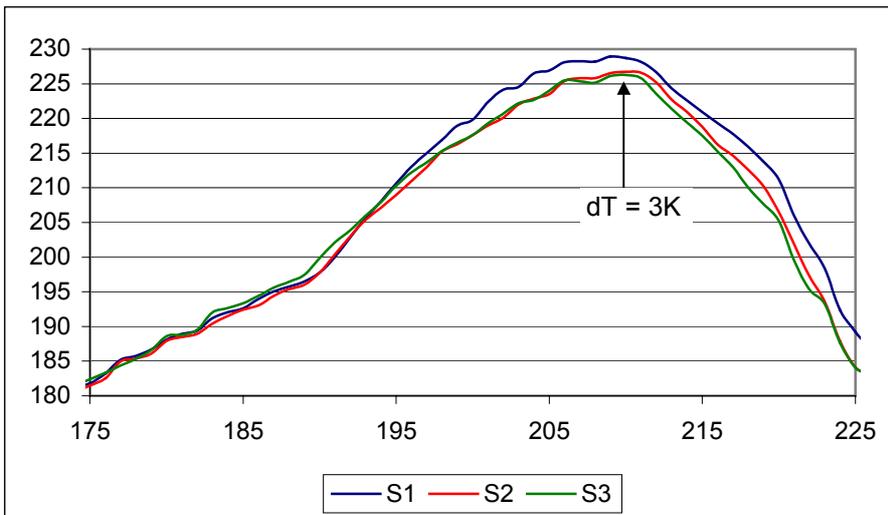

Figure 4-3: cross profile of a convection oven under air, detail of the peak area

4.2 Heating behaviour of the PCB

The therefore used thermocouple is installed directly on a meandering shaped area of the CLF material, that simulates the thermal behaviour of blank PCB material (figure 4-5). Since the measurement area is shaped free of breakthroughs, drill holes and board edges, their influence can be determined in comparison with the cross profile sensors.
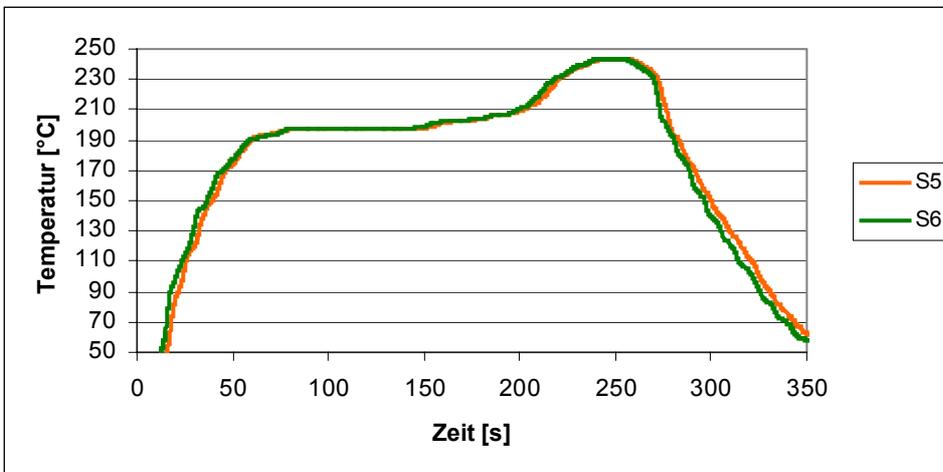

Figure 4-5: heating behaviour of the PCB

4.3 Influence of the bottom heater

In order to be able to describe the influence of the bottom heater integrated in reflow ovens, a thermocouple is installed on the underside of the PTP®. The area of this thermocouple, which is insulated from the remainder of the board, corresponds to the area of middle thermocouple for cross profiles and enables with it a direct comparison of the amount of the heat transfer from below with the amount of heat brought in from above. Hereby, the adjustment of useful parameters can be supported with the utilization of a bottom heater.
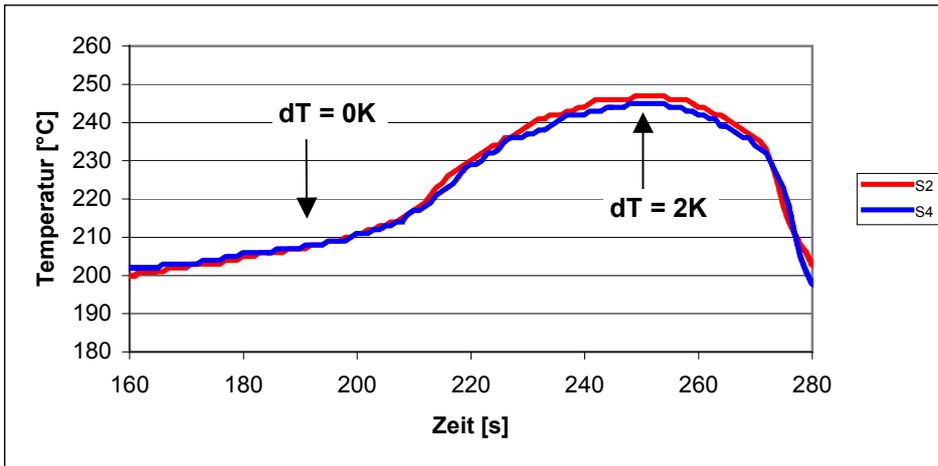
Figure 4-6: bottom heater

Figure 4-6 shows an excerpt from a saddle profile for an unleaded soldering process, which was taken on a convection reflow oven without bottom heater. During the long resting time of approximately 150s on the temperature saddle, a very good balance was achieved between the temperatures above and below at the end of the bottom heater. After the resting time in the peak (without bottom heater), allways an temperature difference dT will be measured. The temperature difference depends on the temperature at the saddle end and the resting time within peak.

4.4   Thermal separation heating zones

What is understood by the term of thermal separation? Most reflow ovens have several regulated heating zones independently adjustable from each other. With that the purpose of being able to realise different temperature profiles in an installation is pursued. This is achieved through varied temperature settings of the single zones and through different transportation speeds of the boards through the oven. However, the result is only satisfactory if different settings can actually influence the profile. By the term of "a good thermal separation", the low reciprocal influence of neighbouring heating zones is understood. At higher temperatures a particular zone emits heat to its neighbouring zones. If the thermal separation of both zones from each other and their control response is not sufficient, this undesirable heat flux will contribute to a temperature increase of the neighbouring zones (see figure 4-7).
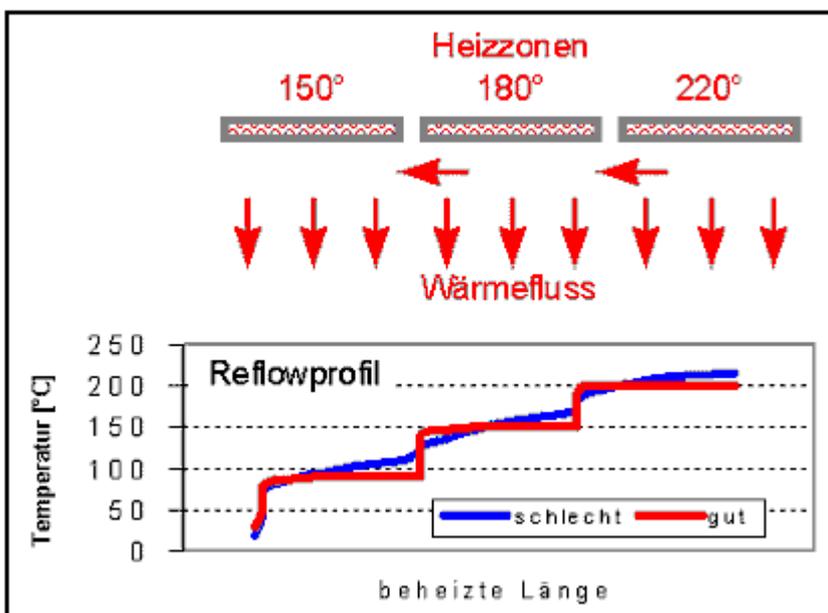

Figure 4-7:   thermal separation

The measurement of the thermal separation takes place with the help of thermocouples which are arranged 6

mm above the PTP surface and measure the temperature of the surrounding atmosphere (gas). One thermo-couple records the maximum gas temperature, since through the existing opening only a minimal heat transmission to the measurement board occurs.

For the measurement, the zonal temperatures of the reflow ovens should preferably increase in equidistant steps, e.g. with 5 heating zones in the steps: 50, 100, 150, 200, 250 °C. If a good thermal separation is proven, the result of the measurement shows a strongly developed stairway profile. The worse the shape of the stairway profile turns out, the more the neighbouring heating zones influence each other.

Figure 4-8 shows the good thermal separation of the zones of a reflow oven that was adjusted for high temperature applications (gas temperature > 300°C).
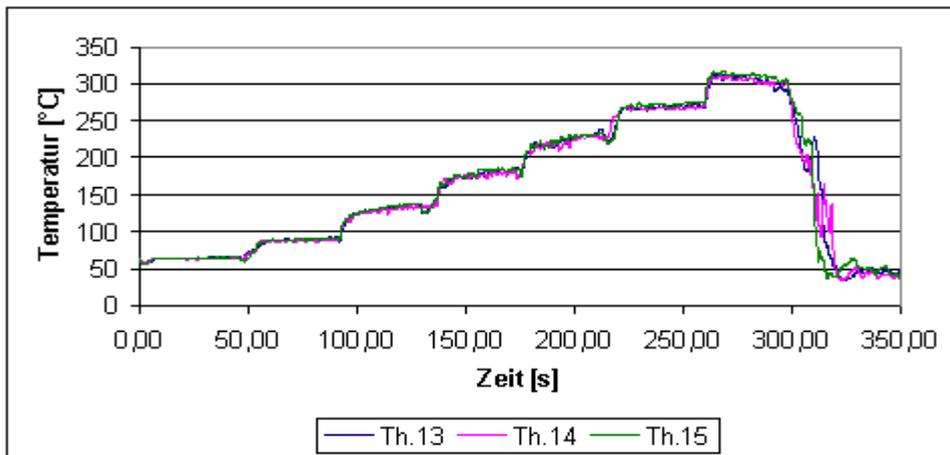

Figure 4-8: proof of the thermal separation

The stairway like shaping of the profile with steep, sharp increases towards to the next higher temperature level meets the requirements of a well designed and constructed reflow oven.

4.5   The influence of the transportation speed

The transmission of heat is linearly dependent on the time. This relationship makes it possible to realise different reflow profiles only through the change of the transportation speeds of the boards through the oven with constant temperatures in the heating zones. For example, the results of higher transportation speeds are lower maximum temperatures, as well as lower dwell times over a certain temperature level. Figure 4-9 shows two temperature profiles that were determined at transportation speeds of 85 and 120cm/min. The time above liquidus, here at 217°C, is reduced in this case from 42s to 31s and the maximum temperature decreases by around 4K.
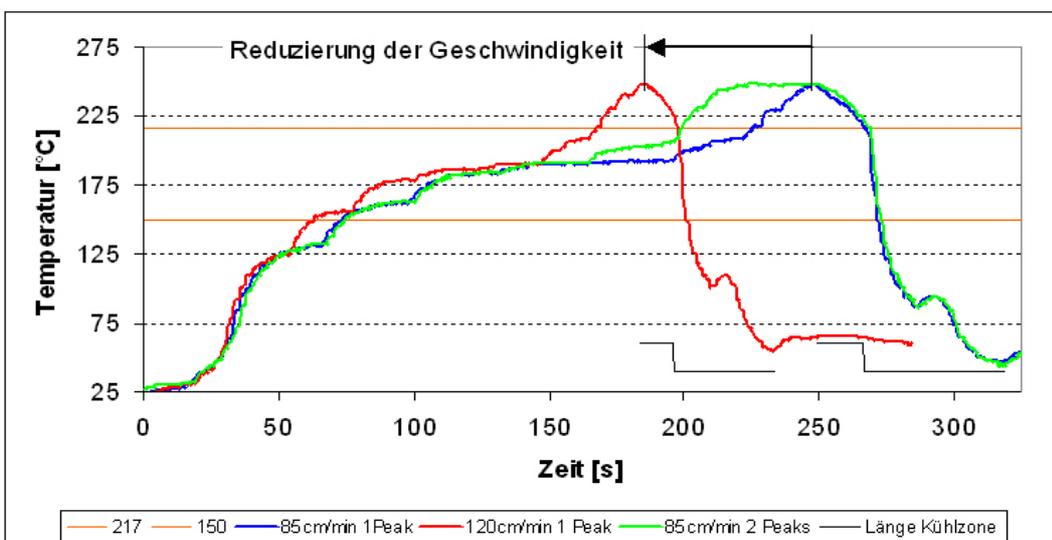

Figure 4-9:   the influence of the transportation speed

4.6 Measurment standards (Reflow)

Too often, no real boards can be used for temperature measurements in the reflow area. There are two important reasons for this amongst other things:

Real boards are usually quite expensive and cannot be withdrawn off production orders for measuring purposes.
Real boards often survive only a few runs through a reflow oven, since components and PCB material are not designed for durability against temperature stresses (for example, FR4 has a glass conversion point in the area of 140-160°C).

Therefore, temperature measurements in the reflow oven using a PTP-measurement standard represent a very good alternative to measurements with real boards. Measurement standards are thermal masses where their heating and cooling behaviour comes very close to the behaviour of real modules. They are constructed so that they withstand stresses in the reflow area.

The variety of boards that can be built from different materials and components show a very varied thermal behaviour during a run through a reflow or a curing oven. It is clear that the construction of the single ovens and the type of heat transmission used in them are also very different. Therefore it is not surprising that the temperature profiles of different boards that were gathered with measurements on the same oven differ from each other. On the other hand, the profiles of the same board determined on different ovens also differ from each other.

The PTP® offers you the possibility to unite the thermal conditions of all of your boards on just one measurement board. To do this, you must only make one assignment of your board to one of the measurement standards on the PTP®. Because of the different physical mechanisms during the heat transmission described earlier, this standard cannot be replaced with a prediction with adequate precision.

The determination of the assignment
If no empirically established values from measurements with the PTP® are currently available, the **first step** is to determine the temperature profiles for the measurement standards. To do this choose the oven settings you require, one after the other, and measure the temperature profiles for the individual measurement standards with the PTP®. As result, you get a group of curves for each oven setting, as can be seen at figure 4-10.
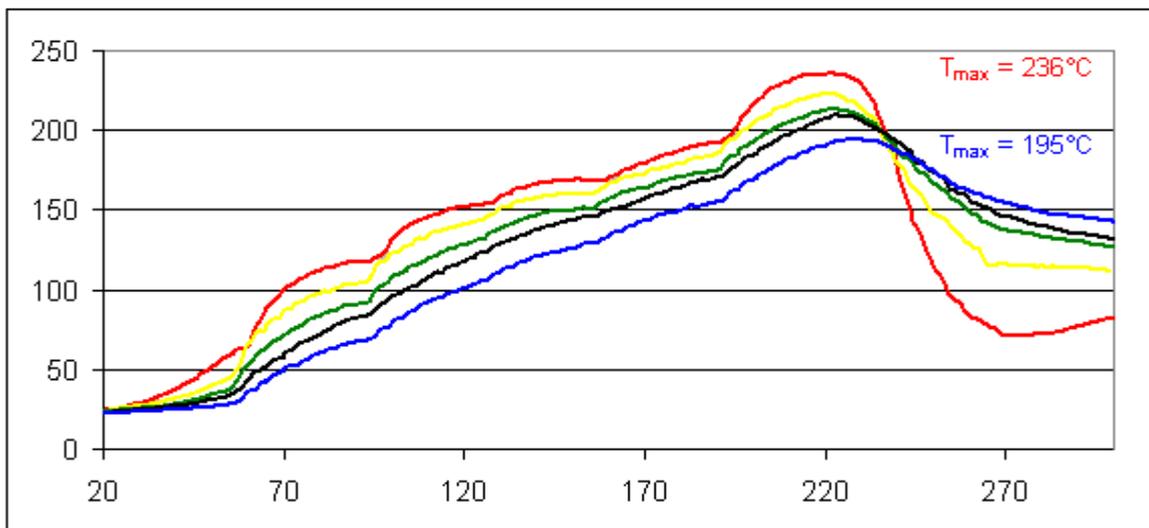

Figure 4-10: Group of curves for different measurement standards

In the **second step**, you measure the temperature profiles of your boards, with an oven setting optimal for each board. To do this, at least two thermocouples are to be fixed at the biggest and the smallest thermal mass (component). In the result you get at least two curves, that reflect the maximum and minimal temperature progression of your board over the oven dwell time.

REMARK If the biggest and smallest thermal mass of your modules are still unknown to you, you can determine these with a simple, well known procedure:
With a given setting for the oven temperature, you change the oven speed with each oven cycle for your board.

Begin with a high oven speed first, from which you can expect that no soldered joint (solder paste-depot) will

melt. Then if you reduce the oven speed step-by-step, more and more soldered joints will melt little by little. The soldered joint, which is already melted at highest speed, is the smallest thermal mass on the board. The soldered joint, which is melting only at lowest speed, possesses the biggest thermal mass on the board.
Often, the person in charge can make this assignment on the basis of his experience.

In the **third step**, you compare the temperature profiles of the board (second step) with the temperature curve groups of the PTP® (first step) that were gained with identical oven settings. See figure 4-11.
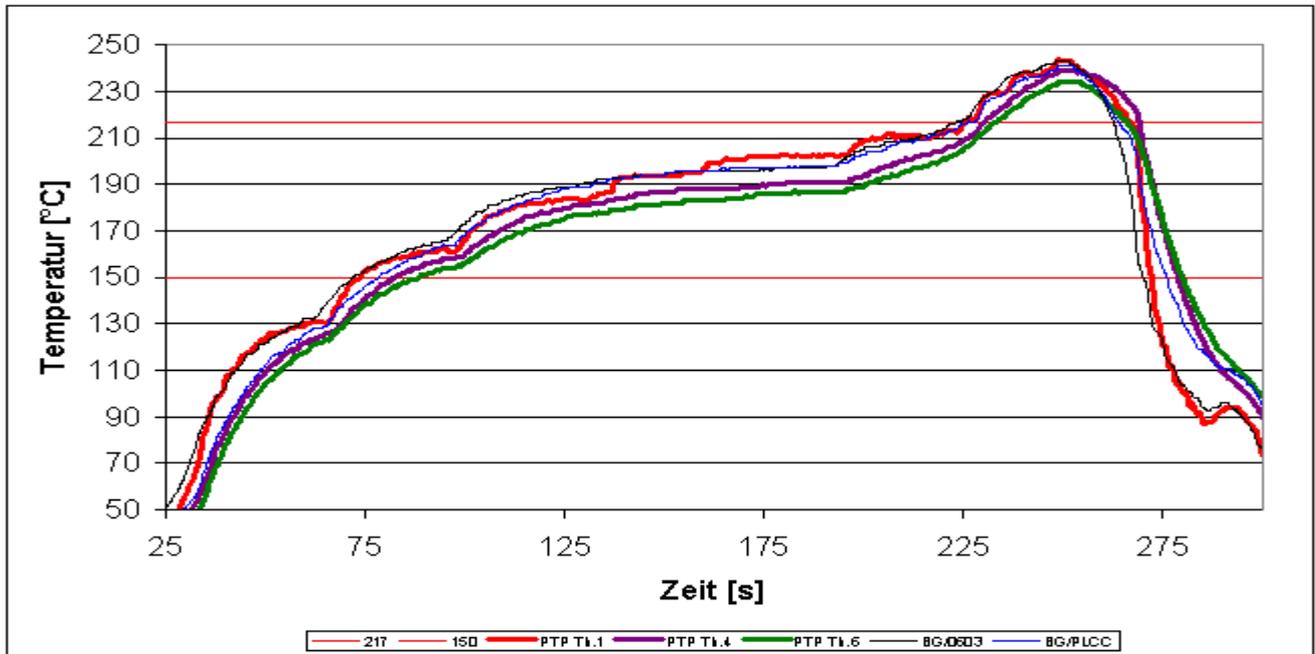

Figure 4-11: comparison of the PTP® standard curves with the temperature profile of a board

If the curves of the measurement standards can be brought to approximate the temperature curves of the board, the assignment is completed successfully. What does "approximate " mean?
The allowable deviation between the curves should be defined before beginning of the measurements (for example ±5°C). On this occasion, it has to be noted that the oven has temperature inaccuracies (e.g. maximum ± 3°C), and that the board possesses a natural dT between the thermal masses located on it (e.g. 8°C) because of its thermal characteristics. These realities must be heeded in the discussions of the curve. It is recommended to envelop the temperature profile of the board between two measurement standard curves. This corresponds to the definition of values for the upper and lower limit (OGW, UGW).
In the figure, the maximum and minimum temperature profiles of the board (0603, PLCC) can be enveloped between two measurement standard curves (green and red).
For all further measurements (for example within the supervision of your production line or with the initial evaluation of new ovens) you can now use the PTP®.

4.7 Vapour phase-/ Condensation soldering

Since the transfer of energy differs in Vapour phase systems from this in convection systems, partly different measuring arrangements are necessary, than they are used otherwise with Reflow soldering systems. The measuring board PTP® Vapour phase considers this. However an influence can be observed by "naturally" convection also with the condensation reflow soldering (fig. 4-12). The gradient sections in the temperature curve of the heating phase suggest dominant factors a portion of the heat transfer by condensation, while the curved sections are affected by convection also. A thermocouple measures the atmosphere temperature during the soldering process. The temperature gradient of this thermocouple obtain an impression over the convective portion of the heat transfer during the soldering process. Liquid drops at the thermocouple, which are condensed there, can undefined drip off, that's why it can come during individual measurements to strong fluctuations of the measured temperature (figure 4-13).
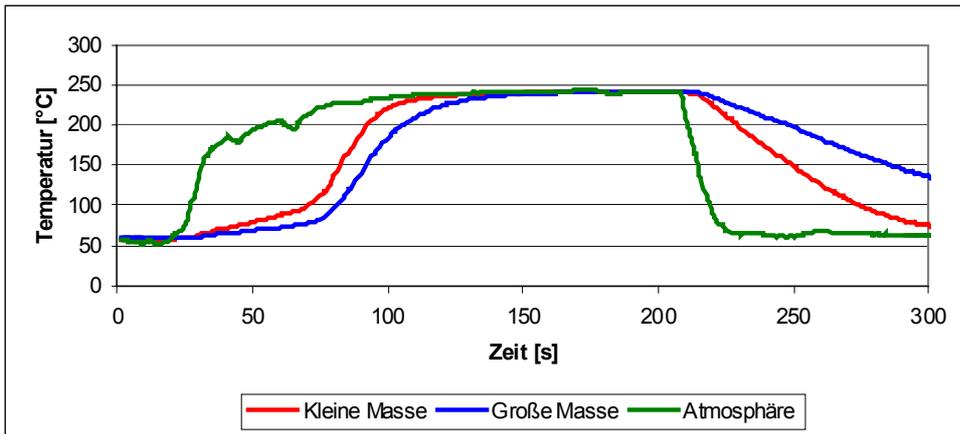
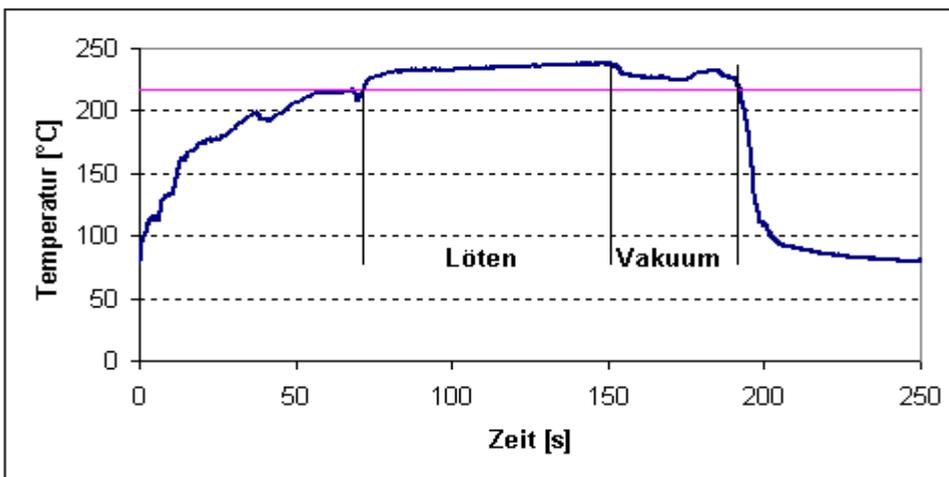*Figure 4-12: Typical temperature curves for Vapour phase soldering.*

Figure 4-13: Measurment of the atmosphere temperature in a condensation vacuum system

Some measuring standards on the PTP® Vapourphase are manufactured from solid metal cylinders. Their heating behavior can be compared with components on different assampled PCB's. The different masses and geometry metal cylinders become fair with the fact that the condensation takes place on all "cold" surfaces. Since the condensed liquid possesses a rather bad thermal conduction, the liquid film remaining on the surface affects the heat transport into the mass (the measuring standard). The liquid film is affected by the geometrical organization of the measuring standards. Two further thermocouples simulate the heating behavior of BGA Packages (above) and of BGA ball (down). Further more thermocouples are placed directly on a thick measuring field of the PTP®. Since the thermal conduction of the board material is relatively small, the results of measurement of both thermocouples obtain an impression over the uniformity of the heat entry over and under the transportation level. A larger temperature difference means a less evenly effected energy impact or heat conduction in the mass of both sides.

5 Wave soldering

5.1 Parallelism wave / transport

The thermocouples for the determination of the parallelism are arranged in a row over the width of the PTP® Wave and exceed 1.5 mm under the transportation level. Their task exists mainly in the collection of the parallelism of the transportation level to the wave level. Due to the adjusted sensitivity of this thermocouple arrangement the reached final temperatures can deviate with a measuring run from the actual temperature of the solder bath (e.g. of 250°C). The measured final temperatures at the thermocouples depend on the adjusted transportation speed and respective wetting time from it. If the determined wetting times and the final temperatures reached with the measuring run are approximately equal, it can be proceeded from the parallelism of the trans-

portation level to the solder wave. If the measuring board dips however on a side of transport more strongly into the solder wave than the determined final temperatures and the wetting times differ from each other between the three thermocouples (figure 5-1). In practice it will give always small deviations in the wetting time, since the wetting front of the solder wave is generally no ideal line. Usually the wetting front is convex curved to the center, whereby the longer wetting times at the thermocouple in the middle of the board are explainable (center). The plant operator/technologist must decide, which wetting time differences are still justifiable, thus with which deviations still useful soldered connections to be produced to be able. Will be the differences too largely the transportation level again must be adjusted. Here it is to be noted that the liquid solder is always "in balance".
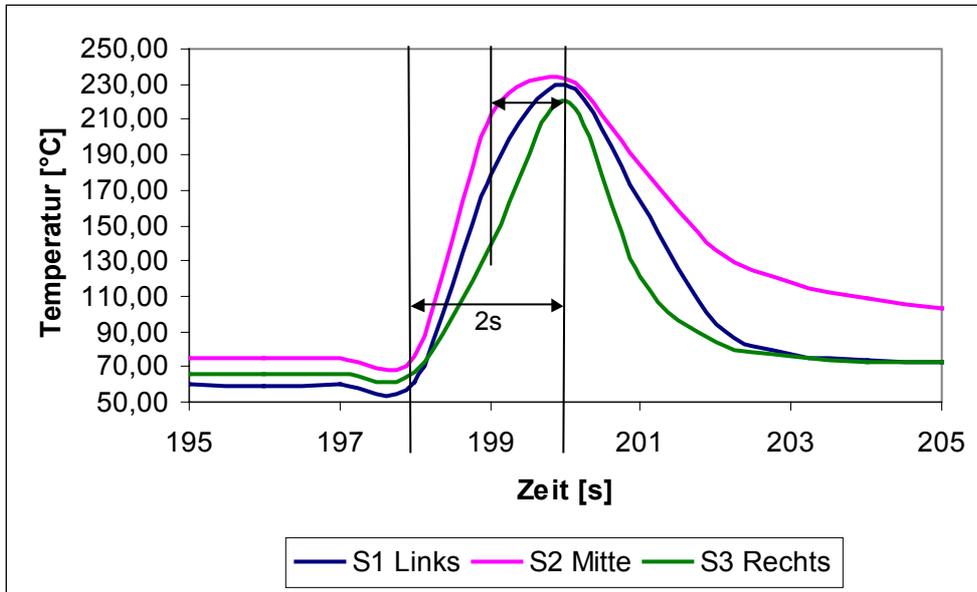

Figure 5-1:   *Wetting times, maximum wetting time 2s,*
                        Wetting time difference between S2 and S3 approx. 1s.

5.2   Solder contact and transportation speed

The thermocouple for the solder contact exceeds 2.5 mm under the transportation level of the PTP® Wave and serves as indicator for the solder contact. With these maximum length (in relation to the other thermocouples) this thermocouple has always the longest contact with the solder wave. In the case of double wave soldering plants two pronounced temperature peaks must be registered. Otherwise is to be assumed the wave soldering plant is completely insufficiently adjusted. The peak for the chip wave can have a smaller maximum temperature, than the peak for the main wave. This depends on the in general substantially shorter time of contact, which the sensor stays in the chip wave. In the main wave however sufficient heat energy flowed into the sensor, in order to register the actual preset temperature of the solder bath. This thermocouple can be used therefore also for the determination of maximum wetting times. Additionally also qualitative statements about the impact of the preheating can be achieved from the measuring data. However here the influence of the printed circuit board base material remains unconsidered.

Very frequently measuring curves of the thermocouple for the solder contact are called wave soldering profile. However it is to be noted that only in connection with the measuring curves of the other thermocouples a comprehensive picture of the soldering parameters is given. Figure 5-2 shows the temperature distribution well adjusted single wave soldering plants. The maximum temperature of 250 °C agrees with the adjusted/expected solder bath temperature (250 - 5 °C). In the main wave the measuring board experiences a wetting time (wetting length) of 4 s.
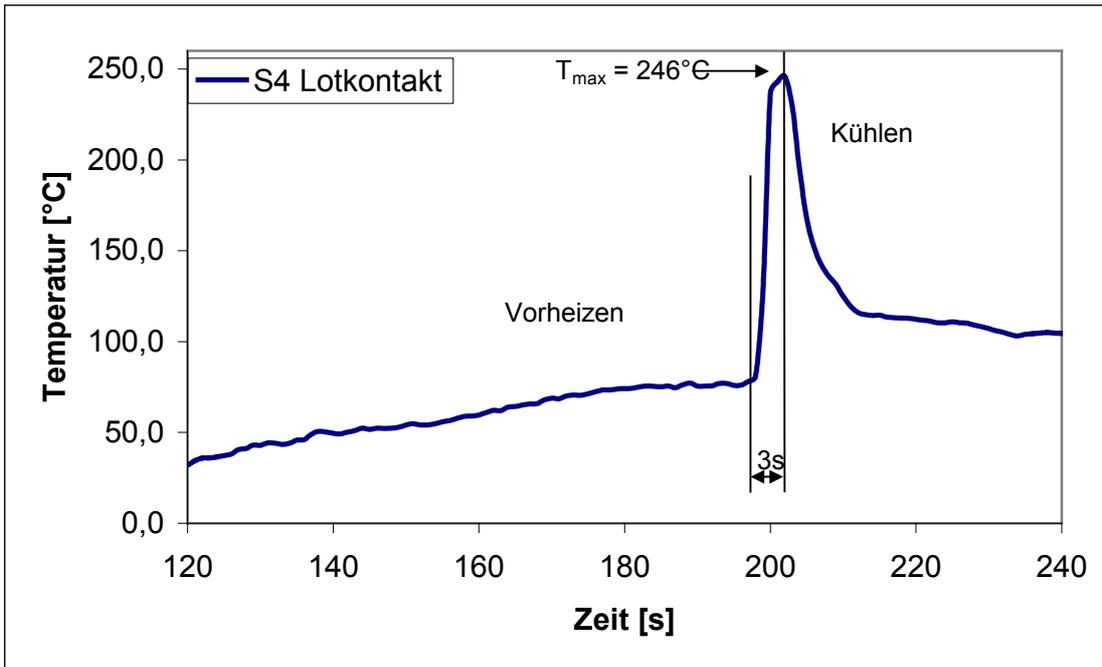
Fig. 5-2: Temperature distribution (well adjusted single wave soldering system).
Maximum wetting time 3s, plumb bob bath temperature 246°C.

The thermocouples for the transportation speed are placed in the defined distance of 100 mm on the PTP® Wave and serve for the examination ofvthe transportation speed on wave soldering plants. On the indication of the target transportation speed of the wave soldering plant in the PTP® software the time offset (for the distance of 100 mm) between the two thermocouples is out-counted, so that in the ideal case the curves of the two thermocouples in the representation lie on top of each other, if the actual transportation speed corresponds to the desired preset value. If a time difference between the temperature peaks of both thermocouples is determined, the measured transportation speed does not agree with the preset value. In such a case the wave soldering plant is to be adjusted again. In the figure 5-3 the time difference amounts to 0 s; the measured transportation speed agrees here with the desired preset value.
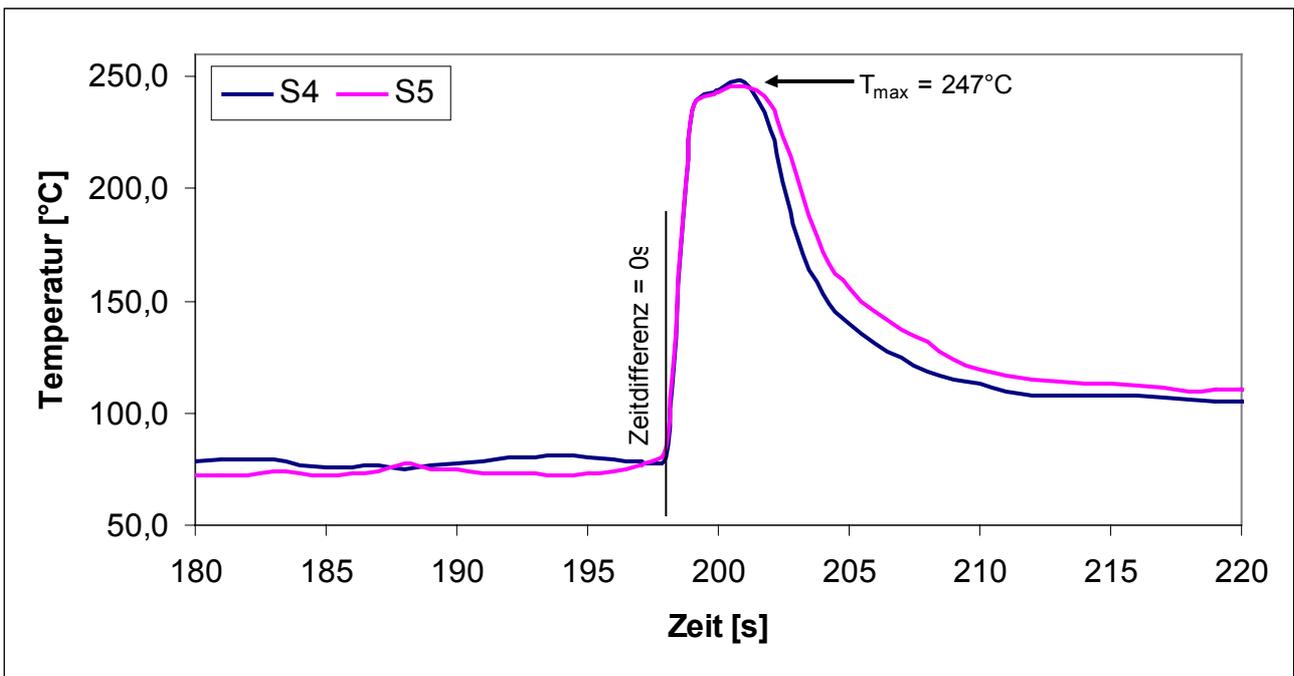

Figure 5-3: Examination of the transportation speed.

5.3 Wave height and wave pressure

These thermocouples are arranged in ranges (stairway steps) of the measuring board with a level, lying over the transportation level, as is to be seen 5-4 in figure.

This measuring setup makes statements possible about the adjusted wave height and the wave pressure. The arrangement in horizontal and vertical direction of the measuring board permits besides statements about the uniformity of the wave pressure about the entire wave width and a defined time. Due to the adjusted sensitivity of this thermocouple arrangement the reached final temperatures can deviate with a measuring run from the true temperature of the solder bath (e.g. of 250°C) clearly. The measured final temperatures at the thermocouples for the wave height depend on the adjusted transportation speed, the Eintauchtiefe as well as the resulting wetting time from it. A contact with the solder wave always leads to a pronounced temperature peak with very steep heating flanks. The peak temperature can lie here clearly below the true solder bath temperature.
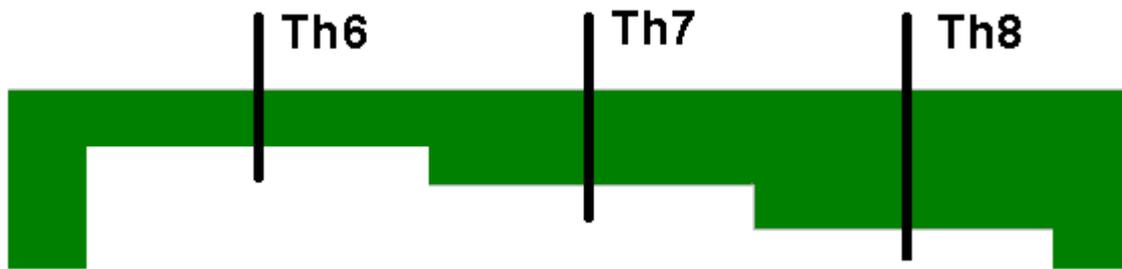

Figure 5-4: Measuring arrangement for the measurement of wave height and wave pressure.

In the figure 5-5 the temperature profiles of an not optimally adjusted wave soldering plant are shown. In the picture a sensor (Th7) still has contact with the solder wave, while the other does not reach the solder wave (Th6). From the very small maximum temperature it is to be read that the existing solder contact was very short.
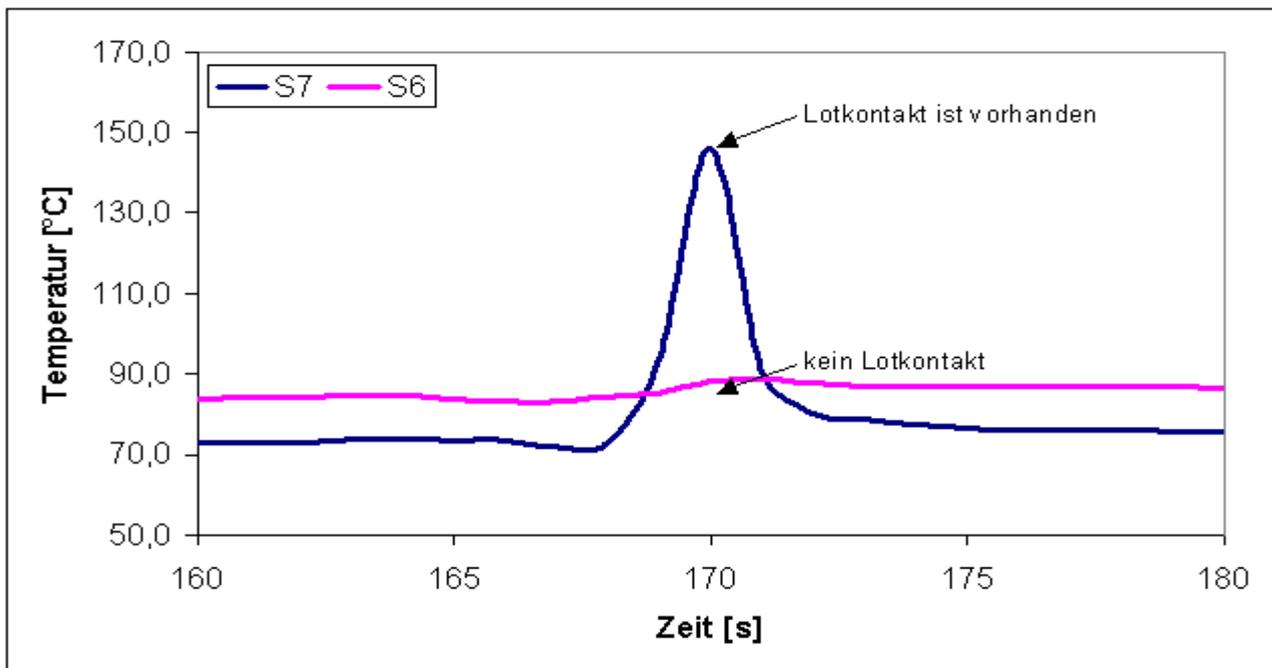

Figure 5-5: Wave height / wave pressure of an not optimized soldering system.

5.4 Atmosphere temperature

The thermocouple for the determination of the temperature of the atmosphere of the wave soldering plant is installed 6 mm over the measuring board surface. In particular with the processing of very critical compo-

nents/devices the knowledge of the atmosphere temperature is extremely important, since it likewise supplies a contribution for the entire heating up of the device. Figure 5-6 shows the atmosphere profile of a soldering plant in the comparison to the soldering profile.
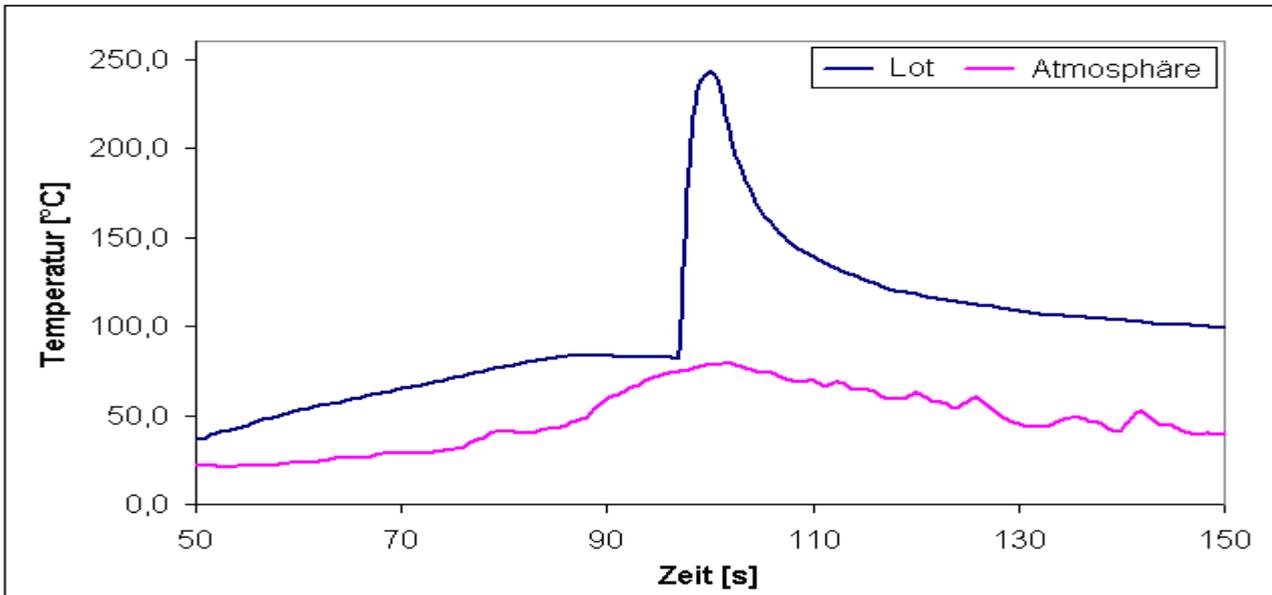

Figure 5-6: Comparison of atmospheres and soldering profile.

5.5 PCB temperature, preheating temperature

Both thermocouples for the determination of the preheating temperature are directly horizontal installed on the measuring board in that 1.6 mm thick range above and down. Since with fluxing agent suppliers often different data are given to the preheating temperature, the knowledge of the printed circuit board temperatures of top side and lower surface is very important. Small devices with direct printed circuit board contact, e.g. chip condensers accept very fast the same temperature as the printed circuit board. Therefore the temperature profiles of these thermocouples can be rated also as temperature distributions of small elements. Figure 5-7 shows two (printed circuit board above and down) preheating profiles.
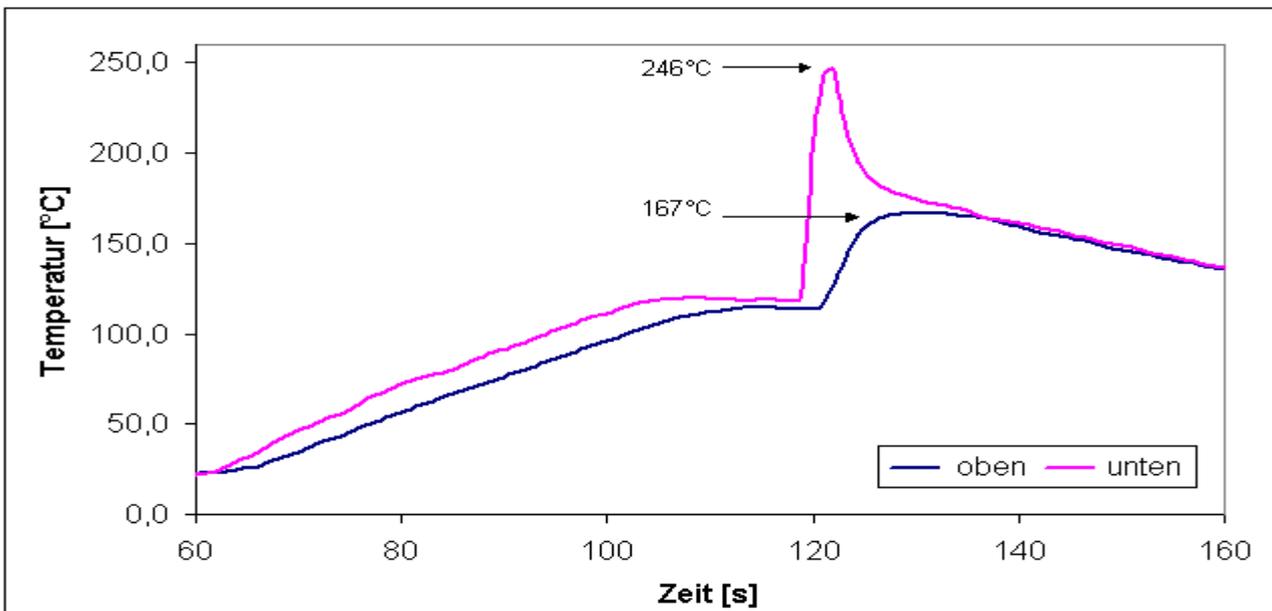

Figure 5-7: Temperature profiles of the printed circuit board (above and down).

5.6 Measuring standards (Wave)

The measuring standards are installed on 1.6 mm thick measuring board ranges. Their task exists in the simulation of the thermal behavior of critical devices like e.g. electrolytic capacitors. Since the thermal masses do not change their characteristics, repetition measurements with the PTP® Wave can be used also for the quality assurance.

The determination of the allocation
The PTP® Wave offers the possibility to you of uniting thermal conditions of many devices or an area of a real PCB's with the behavior of one standard on a measuring board. For this you must make only a unique allocation of your device on the PCB to one of the measuring standards on the PTP® Wave. This allocation cannot be replaced due to the different physical mechanisms during the heat transfer by a forecast, because it had not a sufficient accuracy.

In a **first step** the temperature curves for the measuring standards on the PTP® Wave are to be determined. As result you receive a temperature curve crowd, as they are to be seen in figure 5-8.
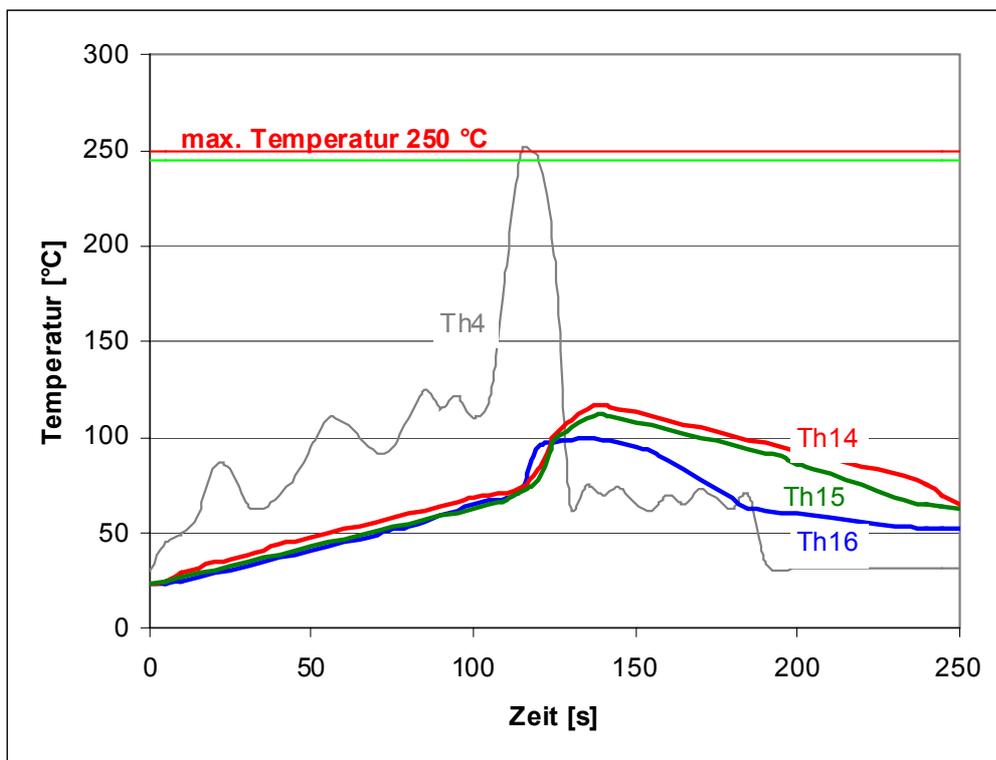
Figure 5-8:   *Temperature curves of the measuring standards in the comparison to the wave soldering profile.*

In the **second step** you measure the temperature curves of your devices of interest on your PCB with the same wave soldering parameters. For this reason thermocouples are to be fasten at the particularly critical and/or noteworthy devices. In the result you receive the temperature profiles of your devices for the selected wave soldering parameters.

In the **third step** you compare both of the temperature profiles. This profiles of the test devices of your PCB (second step) with the temperature curve crowd of the measuring board PTP® Wave (first step), which were measured with identical wave solder plant setting, see figure 5-9.

Figure 5-9: Temperature curves of a real device compared with the measuring standards.

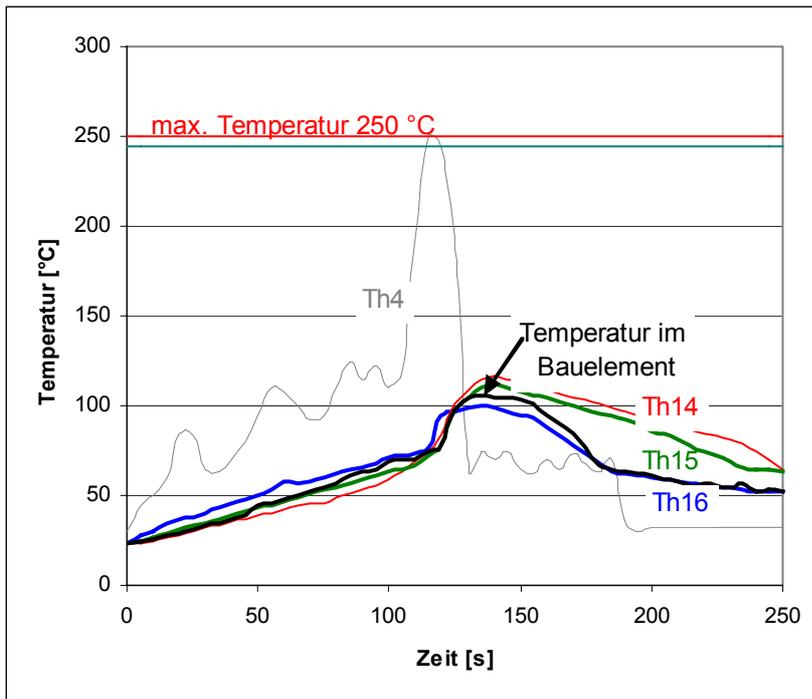If the curves of the measuring standards can be set in comparison to the test device to the approximate covering with the temperature curves, the allocation is successfully finished. What means "approximate covering"?: The allowable variation of the curves from each other should be defined before beginning of the measurements (e.g. 5 °C). Here is to be noted that on the one hand the wave soldering plant has temperature tolerances (e.g. max. 5 °C) and on the other hand every device on the PCB has due to its thermal characteristics a natural tolerance behavior. These conditions must be considered with the curve tracings. It is recommendable to leave the temperature curves of the test device is wrapped by two measuring standard temperature curves. This corresponds to the definition of upper and lower limit values (OGW, UGW). In the picture example the temperature curve of the test device (black) can be wrapped of two measuring standard temperature curves (Th15 green and Th16 blue).

6 Evaluation of Reflow profiles

6.1 Which Reflow profile is optimal?

A frequently asked question in the production world of Surface Mount Technology is that of the ideal temperature profile under which an electronic board should be soldered. It can be answered in many different ways. The manufacturers of some soldering pastes give very specific details about the temperature-time relationship where they expect an optimal soldering result for their paste. The component industry usually specifies the maximum stress limits that a component can be exposed to over short-term or long-term. To be found in the IPC JEDEC 20B are qualification criteria for moisture sensitive electronic components that can be used in an unleaded soldering process:

- **10 to 40s at a maximum of 245 to 250°C**
- **heating gradient ≤+3K/s**
- **cooling gradient ≤-6K/s**

However, the details in the available specifications about soldering ability leave some statements open about the boards, which complicate conclusions for an optimal reflow process with them. Often, only sweeping statements are to be found in the delivery notes of the respective boards that the soldering ability was tested according to J-STD-003 or DIN IEC 68.

More concrete boundary conditions are given by the actual board production in itself, which is found using existing reflow equipment and expected cycle times.

In the sum of these considerations, the ideal reflow profile consists mainly of the demanded profiles of the soldering paste, the components, the PCB and the production realities.

From the thermodynamic viewpoint, during the reflow soldering an electronic board experiences not just one temperature profile but a multiple of profiles, which correspond in each case to an individual place on the board. This group of temperature profiles can be summarised with two curves that represent the maximal and minimal temperature curve in each case. Therefore, the optimal temperature profile for a board must always be described by two "wrapping" curves, which consider all aspects of the components involved in the soldering process.

6.2 How is a profil assessed?

The most important aspect of the opening discussions is that only the producer of an electronic board can be able to describe the wrapping curves for an optimal reflow soldering process. Under contemplation of all influencies everybody should always consider the target is as follows:

Realising a good soldering result with a minimum possible stress (heat quantity) for the components.

A sufficient soldering quality can be achieved with several different input parameters, which the production places worldwide prove every day. The difficulty now exists in that, to assess on the basis of measurable temperature profiles of the module, whether these profiles correspond to the optimum possible configuration in the sense of the discussed puzzle.
The PTP® software enables an objective assessment of the temperature profiles and therefore puts the user into a situation to decide whether the measured profile performs well or badly for the soldering process.

For the evaluation, the following 6 parameters are picked out from the temperature profile (figure 6-1):

Preheating time t_{vor}
Maximum temperature T_{max}
Time above liquidus $t_{über}$
Cooling time t_{nach}
Maximum heating gradient dT/dt
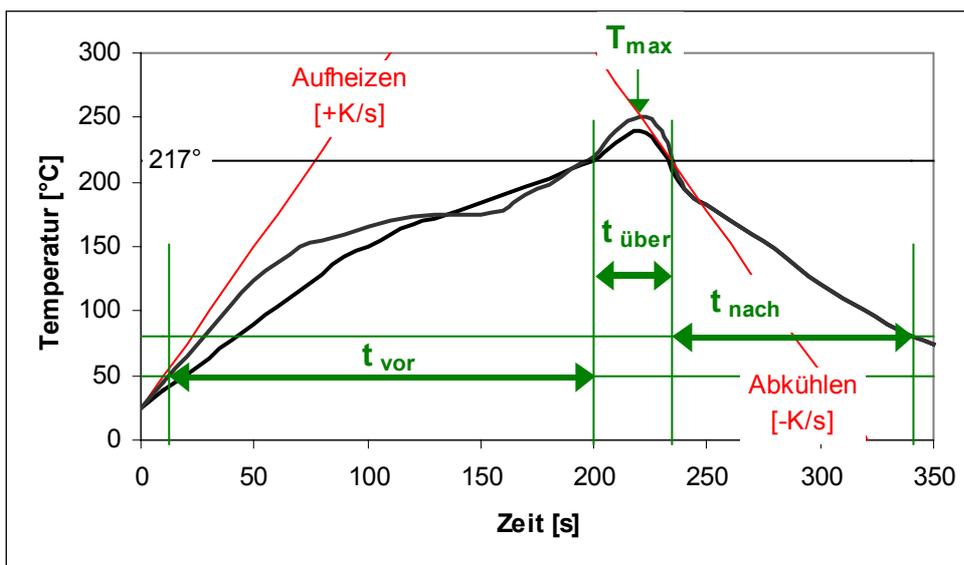**Minimal cooling gradient -dT/dt**

Figure 6-1: scheme of a reflow profile with evaluation parameters indicated

For each of these parameters, upper and lower limits can be defined, outside which the soldering process makes mistakes likely or just cannot work. An example of the maximum temperature is illustrated in figure 6-2:
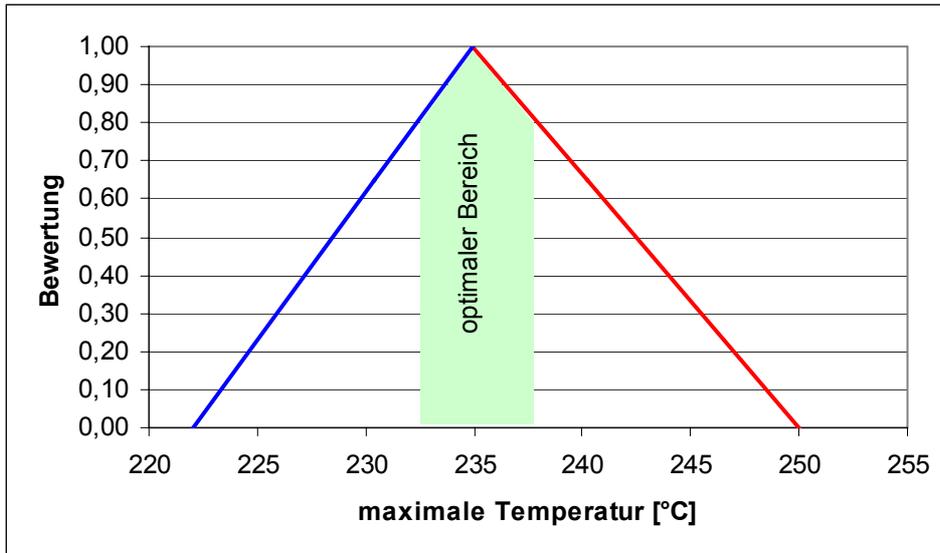
Figure 6-2: evaluation scheme for the maximum temperature parameter for an unleaded process with the SnAgCu solder (melting temperature = 217°C)

The upper limit for the maximum soldering temperature is given through the specified temperature limits of the components at 250°C (according to IPC 20B [14]). The lower limit lies about a measured tolerance above the liquidus temperature of the solder. These two limits bound the necessary condition for the melting of the solder without provoking destruction of the board, therefore this condition must be satisfied. Within the two preset points, which are to be arranged usefully within the limits, one defines the process window and the position of the optimal area. If the numerical value taken from a current profile lies within the process window, the requirements for a successful soldering process are adequately met. In the evaluation scheme, the parameter values are (like the maximum temperature in figure 6-2) applied on the abscissa. On the axis, the standardised evaluation numbers belonging to a parameter value can be read. The evaluation numbers are used for the indication of a tendency in a particular direction a parameter could be changed to improve the reflow process further.

In this way, all named parameters from the temperature profile can be assessed quantitatively. The result is always a standardised value, which results in the optimum in exactly 1 (or 100%) and in the limits in 0 (or 0%). Beside the evaluation of the single parameters, the average value from all evaluation numbers is a score for the entire temperature profile. Since the different thermal masses on the board also lead to different profiles, it is possible to take the average from the weighting numbers of the individual temperature profiles as a performance score for the entire board.

These evaluation numbers enable a quantification of the subjective impression that (for example) two soldering profiles look similar to each other. Besides, they give the user knowledge of which direction a soldering process would be to change, in order to lie in the optimal area.
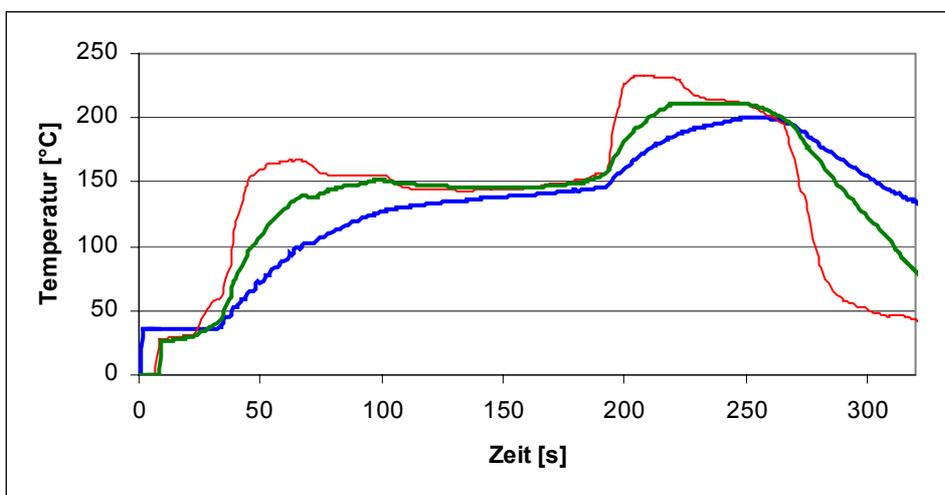

Figure 6-3: saddle profile for a SnPb reflow process

Figure 6-3 shows with the professional Temperature Profiler PTP® recorded and assessed temperature profiles

for a SnPb reflow process. Represented in red is the atmospheric temperature of the reflow oven and in green and blue in each case the wrapping curves for the board behaviour. The average weighting number only reaches a value of 55.9% (without atmosphere).

A glance on the table 6 below quickly makes clear how the process can be changed in order to solder in a more optimal area.

	Bewertung [%]	t vor [s]	t über [s]	t nach [s]	T max [°C]	+dT/dt [K/s]	-dT/dt [K/s]
Grenzwerte		53 - 192	5 - 90	17 - 120	188 - 250	0,5 - 3,0	-0,5 - -6,0
Optimum	80 - 100	80 - 120	25 - 40	70 - 90	210 - 225	1,7 - 2,3	-4,6 - -3,4
Atmosphäre	21,6	169	72	19	232	8,4	-8,0
Große Masse	55,4	179	60	92	200	2,1	-1,5
Kleine Masse	56,4	166	72	69	211	4,7	-2,6
Mittelwert	55,9						

Table 6-1 [13]: Evaluation of Reflow profiles

Particularly for small masses, the risk of violating the heating gradient limit is significant. This large gradient comes about by choosing too high the atmospheric temperature in the bottom heater area of the reflow oven. The weighting number for the big mass reaches only an average, because almost all parameters lie outside the optimum. In order to raise the maximum temperature somewhat, with simultaneous decrease of the dwell times, a linear temperature profile is recommended. Moreover, linear temperature profiles also have other advantages. According to an examination of [15] a smaller number of Tombstones was proven at 0402 components if one had soldered with a linear profile instead of a saddle profile. [16] reports a smaller number of voids during the unleaded soldering if a linear soldering profile is being used.

Figure 6-4 shows an optimised linear reflow profile for a SnPb-process, which reaches with 76.6% a reasonably high average weighting number.
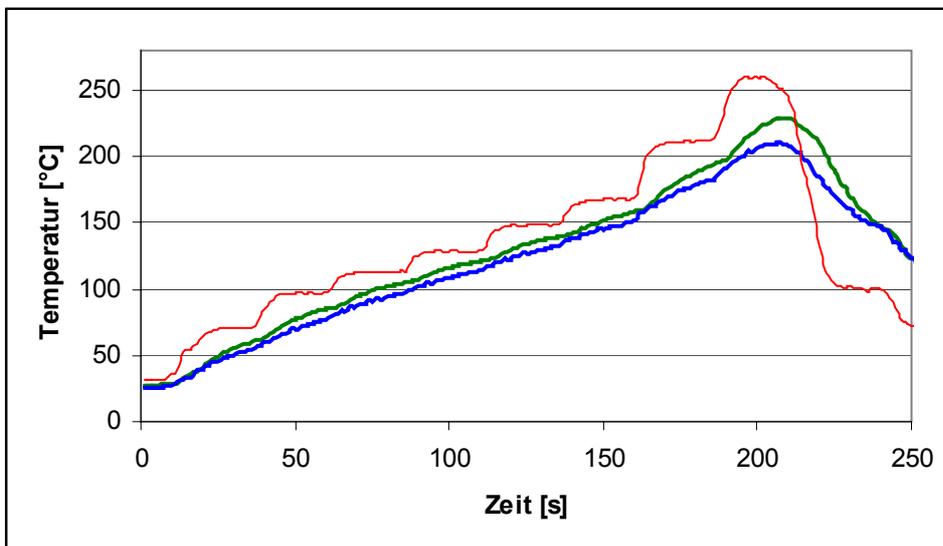
Figure 6-4: linear temperature profile for a SnPb soldering process

The standardisation of the temperature measurement with the PTP® and the evaluation integrated into the software enable a very comfortable measurement, evaluation and ultimately, optimisation of the reflow profiles. The measurement standards on the PTP® are able to calibrate and allow a direct illustration of the real board behaviour with a reproducibility of the measurement and they save the difficult repeated preparation of measurement sensors on the real board.

Figure 6-5: an apparently good temperature profile

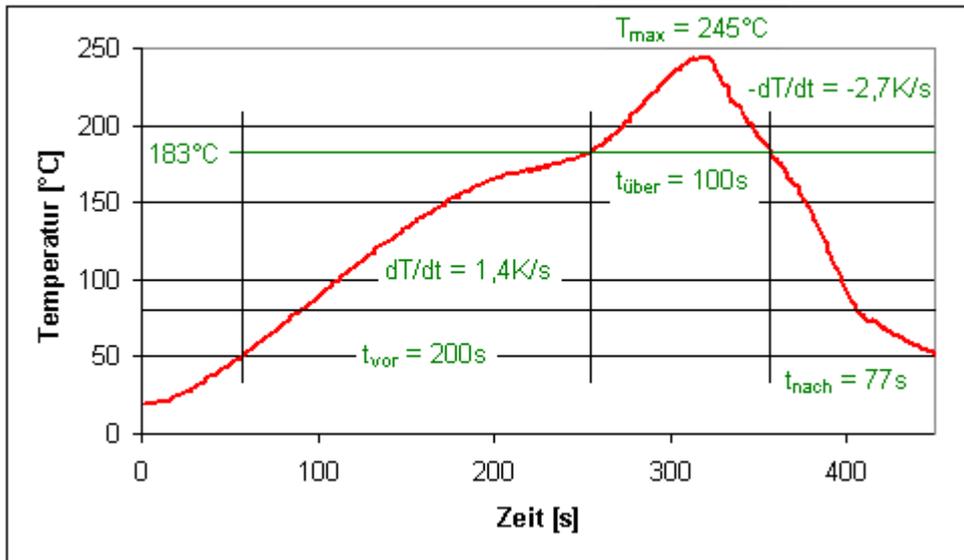Although the first temperature profile on figure 6-5 seems to convey a similar performance as does that on figure 6-4, the more exact analysis shows some weaknesses here that are shown by the following table 6-2.

		t vor [s]	t über [s]	t nach [s]	T max [°C]	+dT/dt [K/s]	-dT/dt [K/s]
Limit values		53 - 192	5 - 90	17 - 120	188 - 250	0,5 - 3,0	-0,5 - -6,0
Meassured values		200	100	77	245	1,4	-2,7
Bewertung [%]	33,8	0	0	75,8	14,9	54,0	58,4

Table 6-2 [13]: Evaluation of a profile (which looks like a good one)

The preheating time as well as the time above liquidus violate the upper limits and are therefore assessed with 0%. The maximum temperature also attains a very low evaluation number, because the upper warning-limit was widely exceeded. An unnecessary temperature stress for the board should always be avoided! The bad evaluation of these three characteristics has strongly influenced the total evaluation of 33.8% for this profile. An improvement of the temperature profile could take place here in a relatively simple way, by increasing the transportation speed through the reflow oven. This shortens the times t_{vor} and $t_{über}$ and reduces through the lesser dwel times in the peak also the maximum temperature.

6.3   The parameter of a Reflow profile

The following sections describe interesting facts about the single profile parameters:

Preheating time
The preheating time t_{vor} is the time between an individual starting temperature (for example 50°C, trigger point of the measurement data logging) and reaching the melting temperature (liquidus) of the solder (for example for Sn63Pb: TLS = 183°C). It is to be optimised under consideration of the following influences. Resins are the active components of the flux in the soldering pastes. Their melting points partially lie between 70 and 120°C, therefore in the region of preheating temperatures. Since at higher temperatures the constant formation of oxide on the metal surfaces of the soldering joints uses flux constantly, it is wise to shorten the preheating phase. Otherwise, the flux could already be used up before the board enters the peak zone (soldering zone), the actual melting zone. However, beside the active substances, the soldering paste also contains a significant number of solvents, thixotropie etc., which boiling points can lie between 125° and 250°C. These substances have nothing to do with the actual soldering process and must have evaporated before the entry into the peak zone. Otherwise, reflow errors like solder balls and voids can arise. Solder balls are caused by explosion-like evaporating of the solvents in the soldering paste and the splattering of grains of paste contained with it. Voids are bubbles in the soldered joint that usually can be traced to gas bubbles of flux components which are not ousted from the soldered joint. The needs of the solder paste must therefore be taken into consideration with the optimisation of

the preheating time, which means the preheating time should also not be chosen too low. During the preheating phase the additional observation of the maximum permissible heating gradients for all components of the board is important. In the reflow area general accepted temperature gradients are at ≤ 2.5 K/s. If the gradient limits are not taken into account, errors like de-lamination and cracking in the substrate or in the package can occur.

Time above liquidus
The time above liquidus $t_{über}$ is the time above the melting point of the solder. On this occasion it must be noted that only eutectic solders possess a defined melting point (for example Sn63Pb T_L = 183°C). Non-eutectic solders have a melting area (for example 92Sn3,3Ag4,7Bi T_L = 210 - 215°C). Information about this gives the phase diagram of the chosen solder alloy or the respective supplier. The time above liquidus is to be chosen so that, on one hand, all of the solder is molten, enough time for the wetting, which means the development of a hem of inter-metallic phases has been given and the liquid solder is able to fill the gap between component and board as well as shape the meniscus. On the other hand, this time should not be chosen too long, to stop the by temperatures influenced accelerated growth of the inter-metallic phase and to keep the dissolve effects within limits. As experience shows, a time of up to 1 minute is optimal.

Cooling time
The cooling time t_{nach} is the time between the solidification point of the solder (intersection of the reflow profile with the liquidus line T_L) and the achievement of the final cycle temperature (for example 80°C, final point of the measurement data logging). The cooling time should preferably be minimized. However on this occasion, the tolerable cooling gradient is to be noted in order to avoid possible damages to any components of the board. If the cooling is too fast, micro-fissures can occur in the package. The purpose of a short cooling time is also to avoid dissolve effects and an undisturbed growth of the inter-metallic phase. At the same time, a small t_{nach} shortens the total resting time of the board on a higher temperature level and with it the stress for all components situated on it.

Maximum temperature
The maximum temperature T_{max} of a reflow profile is often also named the peak temperature. Higher temperatures decrease the surface tension of the liquid solder and therefore improve the flowing behaviour. Experiences from practice have shown that 5 to 10% overheating above the melting point of the solder are advantageous. For SnAgCu, the following T_{max} would therefore be commendable:
T_L = 217°C = 490K
T_{max} = 490K + (0,05 x 490K) = 514.5K, 241.5°C respectively. Partially, the activity of the flux in the solder paste also increases, through which the wetting reaction can run more quickly. At the same time, however, the oxide formation on the surfaces to be soldered also increases, causing more flux to be used. The restriction on the maximum temperature is, in every case, the maximum permissible stress-temperatures and times for the components and the PCP. The JEDEC IPC 20B [14], for example, gives a maximum temperature of 250°C (10 to 30s) for the unleaded soldering process in which the components tested against. In order to reduce the potential for their damage, lower temperature levels are advantageous. Nevertheless, it has to be guaranteed that the solder paste was melted completely and a good wetting of the solder joints was reached. On this occasion, the temperature at the coolest soldered joint is to be noted. The minimum temperature level of T_{max} should not be chosen much lower than T_L + dT_R, in which T_L is the melting temperature of the solder and dT_R are the tolerances in the behaviour of the oven and the inaccuracies in the temperature measurement, to guarantee a safe melting of the solder paste.

Heating and cooling gradients
The temperature gradients dT/dt should be, in each phase of the reflow profile (or at least when heating up), as low as possible, for example dT/dt < 3K/s. In this way, the thermal stress for the entire board (components and PTC) is limited on one hand, and on the other, errors are avoided that are directly connected with gradients that are too steep. The errors associated with this are as follows. Solderballing – due to explosion-like evaporation of solvent components in the solder paste, single solder grains are being hurled out of the paste depot during the melting process. Tombstoning – due to different melting times of the two solder depots at bipolar components, the wetting forces of the already liquid solder cause an erection of the component. Wicking effect – because of excessive amounts of heat transfer into the component connection, the solder of the joint is pulled away from the solder pad and flows upward at the connection. Popcorn effect – due to the fast heat transfer into the component, locked-in moisture (through inappropriate storage of the component) can break the plastic casing. Too low heating gradients are also not recommendable, since the total dwell time of the board is extended by them in the reflow process. Therefore, the production cycle time, as well as the permanent stress levels in the board, increases. During the cooling, the temperature gradient should also be restricted, even if a somewhat faster cooling appears less important regarding the appearance of process errors. In the JEDEC IPC 20B a maximum

cooling gradient of –6K/s is demanded for the components.
Temperature gradients of +2.5K/s and –2.5K/s have found general acceptance in the reflow soldering of electronic boards.

6.4   Resume

In the preceding sections, it was shown that a few typical characteristics of a soldering profile appear sufficient in order to determine the quality of the profile, which means to describe its general suitability for the desired soldering process. The evaluation numbers indicate how far away the respective quantity lies from the limits of the process window. Partially, these limits are restrictive in that a violation of these bounds leads "in all likelihood" to process errors, like, for example, T_{max} the melting temperature of the solder, or the maximum temperature stress tolerance of the most sensitive component. Other limits are "softer ", that means the given numerical values are to be understood more as a recommendation and should also revolve around the realities surrounding the process; for example a moderate shift in the times $t_{über}$ and t_{nach} appears less critical for the soldering process, while the required throughput can necessitate an adaptation of the limits as a boundary condition. In this sense, relevant understanding assumed, the boundaries can be adjusted to the respective process environment (soldering installation, board, throughput, etc) in certain circumstances to fulfil its special quality or feature. The quantitative power of this statement survives as long as the evaluation criteria are chosen usefully and are held equally across a comparison of profiles.

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8. Impressum

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