

METHOD FOR TEMPERATURE REGULATION OF COMPONENTS FOR MAKING A SOLDERED OR SINTERED JOINT, AND SOLDERING OR SINTERING DEVICE

The invention relates to a method for temperature regulation of components for making a soldered or sintered joint between said components, wherein at least one controllable heat source is provided for supplying thermal energy to be transferred to the components.

Furthermore, the invention relates to a soldering or sintering device for making a soldered or sintered joint between components, wherein the soldering or sintering device has at least one controllable heat source configured for supplying thermal energy to be transferred to the components.

Prior Art

It is possible when sintering and soldering for two or more components, in particular electronic components and substrates, to be connected to one another in an electrically and/or thermally conductive manner by means of a joining material, wherein the connecting joining material is sintered or melted on. The components to be connected may be compressed here between an upper tool and a lower tool, wherein the press force is as a rule substantially higher during sintering than during soldering. The thermal energy necessary for sintering or soldering may be transferred to the components via the upper tool and the lower tool in the case of conventional sintering or soldering devices.

Examples of conventional sintering or soldering devices and corresponding methods are described for example in DE 10 2006 034 600 B4, DE 203 00 375 U1, DE 10 2004 047 359 B3, DE 10 2012 206 403 B3 and WO 2014/135151 A2.

The devices or installations used for making soldered or sintered joints may have one or more process chambers in which the process atmosphere needed for performance of the soldering or sintering method may be set and in particular also altered during the process. The components to be connected, which are combined into assemblies beforehand and may if necessary be fixed relative to one another in suitable manner and by suitable means to maintain the required positions, may be conveyed to, from and between the different process chambers by suitable conveying means. The process atmosphere in a respective

process chamber may for example be set and/or altered in respect of its material composition, its pressure and/or its temperature. For example, pressures of between 1 hPa and 1200 hPa may be settable using differing process gas mixes.

In conventional soldering or sintering devices, thermal energy may be input via the upper tool and/or the lower tool. As a general principle, variably spaced heated plates or infrared radiators may also be used as the heat source. A further possibility for heating the components is to input the thermal energy into the components or into a suitable carrier plate by induction. To do so, one or more induction devices may be arranged in the process chamber above and/or below the components to be connected. This creates corresponding induction zones, which are designed such that the electromagnetic energy generated by the induction device is input into the components, and eddy currents are generated there which heat the components. To cool the induction devices, they may be connected directly to a coolant circuit through which a fluid flows, with cooling also being possible by thermal contact with walls of the process chamber. Cooling by convection is also possible.

As a general principle, the distance of the induction devices to the components or to the carrier plate may be altered to optimize the heat input or energy input in the case of different qualities of the components. To do so, the existing induction devices may be lifted or lowered, jointly or individually. Furthermore, there is the possibility to adapt the shape of the induction devices to the shape of the components or of the carrier plates for an optimized energy input.

In comparison with component heating by means of heat radiation or thermal contact, energy input by induction is very easily controllable. With induction devices, the heat input is steplessly controllable between zero power and maximum power within fractions of a second.

In order to exploit the use of heat sources in which the input of thermal energy can be adapted in a highly dynamic manner, as is possible in particular using the aforementioned induction devices, for temperature control which is precise and differentiated in terms of both time and space, it is necessary to provide adapted control of the heat source where delays during heat transmission inside the components are also to be taken into account. Exact measurement of the component temperatures is of great importance here.

Conventionally, the component temperature is measured by one or more temperature sensors which are in thermal contact with the components, i.e. the temperature sensor rests against the component to be measured or is integrated into it. If the place at which the thermal energy is input into the component is at a distance from the place where the temperature is measured, a time-lag between the energy input and the temperature measurement may ensue due to the limited thermal conductivity of the components, which may lead to imprecise control of the component temperature and to thermal overloading of the components due to “overshoots”.

In order to reduce imprecision of this type, the place of temperature measurement may be selected such that it is as close as possible to the place of energy input. The control of the heat source can then react quickly to temperature changes, however the actual temperature of the components cannot be measured very precisely, as they are subjected to thermal energy not directly, but indirectly via a thermal coupling and hence with a time-lag.

DE 10 2004 047 359 B3 proposes the use of a contactless optical measuring system, for example a pyrometer, for temperature measurement. However, optical measuring systems of this type have the drawback that the measured temperature is not absolute, but depends on the material properties and surface properties of the components.

DE 11 2008 000 853 T1 describes a temperature measurement in a heat treatment chamber with a heating element, a component, a contacting temperature sensor and a non-contacting temperature sensor. The non-contacting temperature sensor is arranged outside the heat treatment chamber, and the temperature points for recording the temperature of the contacting temperature sensor and of the non-contacting temperature sensor are almost identical, so that a difference in a measured value of the non-contacting temperature sensor can be eliminated by the measured value of the contacting temperature sensor. The shape stability and the sensor mass are very low, which entails the disadvantage that a measurement gap is created, with the result that changes in the molecule number quickly have an effect on temperature changes.

Description of the invention

The object of the invention is to indicate a method for temperature regulation of components for making a soldered or sintered joint between the components which permits precise

setting of the component temperature and a flexible arrangement of the temperature sensors. This invention is furthermore intended to compensate for interference effects of pressure / gas fluctuations on the contactless sensor.

The object is achieved by a method having the features of claim 1. Advantageous developments of the method are indicated in the dependent claims.

A method is proposed for temperature regulation of components for making a soldered or sintered joint between the components, wherein at least one controllable heat source is provided to supply thermal energy to be transferred to the components. A first temperature of a component or of a component part of a soldering or sintering device in thermal contact with a component is contactlessly measured at a first temperature point by means of at least one first temperature sensor which is in thermal contact with the component or with the component part, and a second temperature of a component or of a component part of a soldering or sintering device in thermal contact with a component is contactlessly measured at a second temperature point by means of at least one second temperature sensor. The first temperature point is spatially distant from the second temperature point such that a temperature gradient between the first and second temperatures in the event of a temperature change may be expected. The measured second temperature is calibrated on the basis of the measured first temperature in order to determine a calibrated second temperature, wherein the heat source is controlled at least on the basis of the calibrated second temperature. Measurement of the first and second temperatures is performed preferably at different places. The component part(s) of a soldering or sintering device which are in thermal contact with a component and are referred to in the following as device components for short, may for example be carrier plates, carrier frames or component carriers, which carry the components to be connected during the manufacturing process. The first temperature may also be additionally determined by a temperature sensor, which is integrated into a component and is connectable to a control unit designed for performance of the method in order to transmit the first temperature of a component to the control unit. If therefore the first temperature of a component or of a device component is measured by several first temperature sensors, the first temperature may be determined in suitable manner, for example by averaging the temperatures measured by the several first temperature sensors, or by other methods. The same also applies for the second temperature.

The spatial distance between the first and second temperature points means that the latter are in any event spatially distributed, i.e. either arranged on one side of the components at a spatial distance to one another, or arranged on opposite sides of the components. The first and second temperature sensors can thus be at a distance of at least 5%, in particular 10%, of the component diameter when arranged on the same side of the components. In any event, it can be expected in a heating-up phase or cooling-down phase that the first and second temperature sensors measuring at different points record measured values that indicate a temperature gradient. In a thermal balance, i.e. during a longer dwell time at constant temperature conditions, the temperature gradient can become smaller or disappear entirely. However, it can be expected, when at least the heat input from the heat source changes as during the heating-up phase or cooling-down phase due to the spatial distance, that the first and second temperature sensors record different measured values. In any case it cannot be assumed that the first temperature sensor records the same measured value as the second temperature sensor, therefore a calibration of the second temperature sensor by the first temperature sensor within the scope of a temperature gradient in the event of a temperature change may be enabled, in particular in the case of dynamic temperature conditions. Advantageously, high flexibility can be achieved for the arrangement by the spaced arrangement of the temperature sensors, such that the second temperature for control of the heat source can be recorded preferably by the second temperature sensor on a side of components or a component carrier facing the heat source, as a component part in thermal contact with the component, while the first temperature sensor can be arranged at a point on the components or the component carrier which is mechanically easy to access for recording the first temperature. A spaced arrangement thus enables a precise calibration of the second temperature of the second temperature sensor by the first temperature of the first temperature sensor even in cramped conditions or with difficult-to-access temperature points; it is also possible to use temperature sensors already integrated in the component, for example, as first temperature sensors.

In the method in accordance with the invention, the first and second temperatures are therefore combined in suitable manner in order to achieve an optimum temperature control at the components. Preferably, the first and second temperatures are measured in such a way that neither temperature substantially changes for a defined period of time, so that the influence of time-lags during heat equalization inside the components, or between the components and the device components in contact with them, can be largely reduced. The first and second temperatures can be measured at the same component or at the same

device component part or at different components or device component parts and in any event at two spatially distant temperature points.

In this connection, calibration means the sum of those activities which are used, under specified conditions, to determine the correlation between the measured values for the quantity of temperature provided by the second temperature sensor with the associated measurement uncertainty and the measured values of the first measuring sensor as the reference temperature sensor with the associated measurement uncertainty. By means of this correlation, the influence of the spatial distance between the first and second temperature points may be taken into account, as well as further differences arising from the measurement technology.

Determining a calibrated second temperature addresses in particular the fact that with contactlessly operating temperature sensors, the measured second temperature as a rule diverges from the actual temperature at this measurement point, which must be ascribed to the fact that a contactlessly measured temperature may vary due to material properties and/or surface properties of the component or of the device component part of which the temperature is being measured.

According to a preferred embodiment, the method is performed in a settable process atmosphere, wherein setting of the process atmosphere comprises at least the setting of a material composition, a pressure and/or a temperature of the process atmosphere. For example, the process atmosphere may contain reactive or non-reactive process gases depending on the respective stage of the process. If the temperature of the process atmosphere changes, this temperature change may also be incorporated into the control of the heat source.

According to a further preferred embodiment, the first temperature sensor is selected from a group comprising at least NTC resistors, PTC resistors, semiconductor temperature sensors, thermocouples and resonant circuit-based temperature sensors. Alternatively or additionally, the second temperature sensor is a sensor configured for detection of heat radiation, and is preferably selected from a group comprising at least pyrometers, bolometers and thermopiles. The sensor types mentioned by way of example for the first temperature sensor(s) represent typical examples for contact-based temperature sensors.

Accordingly, the sensor types mentioned by way of example for the second temperature sensor(s) are typical contactlessly operating temperature sensors.

According to a further preferred embodiment, the at least one heat source is configured for contact-based or contactless heat transfer to the components or to the one or more of the component parts mentioned. The heat source is preferably selected from a group comprising generators of electric, magnetic or electromagnetic fields, preferably heating plates, induction heating elements or infrared radiators, which are couplable at least thermally, inductively or capacitively to the components or to the component part(s) mentioned. The list of possible heat sources is not conclusive. It has however become apparent that generators of magnetic fields, which may also be referred to as induction devices or inductors, inductively couplable to the components or to the component part(s) mentioned, are particularly suitable. With induction devices of this type, the heat output may be controlled in a variety of ways, for example by changes in the operating voltage, in the operating current or in the frequency.

According to a further preferred embodiment, the heat source is controlled in a process step comprising the making of the soldered or sintered joint, and the calibrated temperature is determined in at least one calibration step preceding the process step, wherein the calibration step comprises the generation and storage of a respective calibration function, on the basis of which the calibrated second temperature is determinable from a measured second temperature. The calibration step may for example be performed in that in the case of two different component temperatures or component part temperatures, the first and second temperatures are measured in each case, in order to then determine the calibration function from the measured values. It is also possible to perform several calibration steps, in each of which several calibration functions are determined. This may for example be achieved in that the calibration function is generated and stored specifically for each component or for each component part.

According to a preferred embodiment, the calibration step is performed prior to each performance of a process step, wherein control of the heat source is performed in the process step on the basis of the previously determined calibration function. It is not necessary here for the properties of that component or that device component at which the second temperature is measured to be known in order to select a suitable calibration function. The prior performance of the calibration step before performance of the process

step ensures that the temperature progression cannot lead to component damage due to errors in selecting the calibration functions.

Alternatively or additionally, the calibration step may additionally also be performed once or more during the process step, preferably at defined points in time or at points in time where the temperature of the components or of the device components does not substantially change. The aforementioned performance of a calibration step at points in time where the temperature of the components or of the device components does not substantially change relates to the performance of a calibration where a temperature curve of the components or of the device components has plateaus with different temperatures in each case. This serves to wait out a defined equalization time, in order to eliminate latencies resulting from the different temperature measurement principles and from the spatial position of the measurement points.

In this connection, it has proved advantageous when, prior to performance of a process step, a calibration function matching the components to be processed is selected from a plurality of calibration functions stored in component-specific or component part-specific manner, wherein control of the heat source in the process step is performed on the basis of the selected calibration function. As a general principle, one calibration function may also be selected initially, which can then be checked and/or adapted during performance of the process step.

In accordance with a further advantageous embodiment, the calibration function is a linear function or a polynomial function, preferably of the fourth degree. The use of a linear function has proven to be easy for calculation, wherein any inaccuracies that might arise here can be tolerated. A polynomial function, in particular a polynomial function of the fourth degree, is particularly suitable for calibrating the measuring characteristics of a pyrometer.

In accordance with a further advantageous embodiment, control of the heat source is achieved in a two-stage method, wherein a modified setpoint temperature is determined in a first stage on the basis of the measured first temperature and a preset setpoint temperature, and wherein an output from the heat source is controlled in a second stage on the basis of the measured or calibrated second temperature and the modified setpoint temperature. Such a two-stage control is also referred to as cascade control. The preset setpoint temperature does not necessarily have to be a fixed setpoint temperature, instead

a curve or a ramp of the setpoint temperature may be used as a basis. In particular, the expressions “on the basis of the measured first temperature, of the preset setpoint temperature, of the measured or calibrated second temperature and the modified setpoint temperature” are limited not only to absolute values of the said variables, but also expressly include their respective curves over time, i.e. in particular their mathematical derivations with respect to time. Furthermore, determination of the modified setpoint temperature on the basis of the measured first temperature and the preset setpoint temperature does not rule out that further parameters or measured values may be incorporated into the determination of the modified setpoint temperature if necessary. Accordingly, controlling the output of the heat source cannot be exclusively on the basis of the measured or calibrated second temperature and of the modified setpoint temperature. Instead, further parameters or measured values may be incorporated here too. In particular, feedback into the respective control loops may also be provided in every stage of the two-stage method.

According to a further preferred embodiment of the method, the components to be connected are arranged in a main extent plane, wherein the first temperature sensor is arranged on the one side of the main extent plane, and the heat source and the second temperature sensor on the other side of the main extent plane. Whereas the second temperature sensor and the heat source are here arranged on the same side of the component arrangement, and hence changes of the component temperature can be recorded with a very short time-lag, the first temperature determined by the first temperature sensor is subject, due to its spatial arrangement, to a certain latency that results from the heat conduction inside the component(s) or device component(s).

Alternatively, the first and second temperature sensors may be arranged on the one side of the main extent plane and the heat source on the other side of the main extent plane. Further, the first and second temperature sensors and the heat source may be arranged on the same side of the main extent plane.

The invention relates in a further aspect to a soldering or sintering device for making a soldered or sintered joint between components, comprising at least one controllable heat source which is configured to supply thermal energy to be transferred to the components; at least one first temperature sensor at at least one first temperature point and which is thermally contactable to a component or to a component part of the soldering or sintering device thermally contactable to a component and is configured to measure a first

temperature of the component or component part; and at least one second temperature sensor at at least one second temperature point and which is configured to contactlessly measure a second temperature of a component or of a component part of the soldering or sintering device thermally contactable to a component. The first temperature point is spatially distant from the second temperature point, such that a temperature gradient between the first and second temperatures may be expected in the event of a temperature change. A control unit, which is connected to the heat source and to the first and second temperature sensors, is configured to perform the method according to any of the preceding claims. As already mentioned above, the first temperature sensor or a further first temperature sensor may be a temperature sensor which is integrated into a component and is connectable to the control unit in order to transmit a first temperature of this component to the control unit.

According to a preferred embodiment, the heat source has a measurement window which allows infrared radiation emitted by the components or by the component part(s) mentioned of the soldering or sintering device to pass in the direction of the second temperature sensor.

According to a further preferred embodiment, a tube facing at least in the direction of the second temperature sensor is arranged in the measurement window and is configured to guide infrared radiation emitted by the components or by the component part(s) mentioned of the soldering or sintering device in the direction of the second temperature sensor and preferably to shield the second temperature sensor from infrared radiation which was not emitted by the components or by the component parts mentioned.

According to a further preferred embodiment of the soldering or sintering device, the components, the at least one heat source, the at least first temperature sensor and the at least second temperature sensor are arranged in or on a gas-tight process chamber with a settable process atmosphere, in particular a vacuum, wherein the second temperature sensor is preferably arranged on a side of the heat source facing away from the components. In other words, the soldering or sintering device may comprise at least one gas-tight process chamber in which a process atmosphere, e.g. a low-oxygen or oxygen-free atmosphere, in particular a vacuum, is settable, so that the components can be heat-treated, in particular soldered or sintered, oxidation-free. Both the first and the second temperature sensors are arranged in or on the process chamber, so that the measured

value signals of the temperature sensors are transmitted as first and second temperatures to outside the process chamber. The second temperature sensor can be arranged inside or outside the process chamber, and in the latter case the second temperature sensor may observe the second temperature point through an optical window in the process chamber wall. A control unit, preferably arranged outside the process chamber, calibrates the second temperature on the basis of the first temperature and controls the heat source on the basis of the calibrated second temperature. This enables exact heat source control to be achieved, which may be used for example to comply with a definable temperature gradient between the first and second temperature points.

Drawing

Further advantages emerge from the following drawing description. The drawing shows examples of the invention. The drawing, description and claims contain numerous features in combination. A person skilled in the art will expediently also consider the features individually and combine them into meaningful further combinations.

In the figures:

- Fig. 1** shows a schematic sectional view of a soldering or sintering device in accordance with one example,
- Figs. 2 and 3** show schematic sectional views of soldering or sintering installations in accordance with further examples,
- Fig. 4** shows a diagram with two exemplary temperature curves of a first temperature and of a second temperature,
- Fig. 5** shows a schematic diagram explaining the determination of a calibration function for the second temperature;
- Fig. 6** shows a schematic block diagram of a two-stage temperature control;

Fig. 7 shows a diagram with various exemplary temperature curves and a curve of a relative heat output; and

Fig. 8 shows a diagram with further exemplary temperature curves and curve of a relative heating output.

The same reference numerals have been used in the following for identical or similar elements.

Fig. 1 shows in a schematic and simplified sectional view a soldering device 10 in accordance with one example. The soldering device 10 comprises a dish-like conveying frame 14 open to the bottom, into whose opening on the bottom side a component carrier 12 is placed, which represents a component part of the soldering device 10. Components 16, 18 to be connected are placed on the component carrier 12. The components 18 may be for example substrates which are each to be connected to several components 16, for example power semiconductors, by the soldering operation. A joining material (not shown) may be provided between the components 16 and the components 18 respectively. Below the conveying frame 14 with the component carrier 12 arranged therein, an induction device 20 is arranged which is configured to generate a strong magnetic field which can induce eddy currents at least in the component carrier 12. These eddy currents effect heating of the component carrier 12. It goes without saying that other heat sources may also be provided instead of the induction device 20. The distance between the component carrier 12 or conveying frame 14 on the one side and the induction device 20 is variable.

The soldering device 10 further has a first temperature sensor 24 at a first temperature point, in this case on an upper side of a substrate as the component 18, which is passed through the conveying frame 14 and is in spring-loaded contact with one of the components 18 and which is configured to measure a first temperature.

The induction device 20 has a measurement window 22, which allows infrared radiation emitted by an underside of the component carrier 12 as the second temperature point to pass in the direction of a second temperature sensor 26 arranged underneath the measurement window 22, allowing a second temperature to be measured by means of the second temperature sensor 26. In this example, the first and second temperature points are arranged on opposite sides of the component carrier 12.

Preferably, the first temperature point can be a surface of a component 18. The second temperature point can preferably be a surface of a direct or indirect heat input (e.g. radiant heat) of the heat source 20 on the underside of the component 18 or of a component carrier 12.

The first temperature sensor 24 is designed as a contacting temperature sensor and may be an NTC resistor, PTC resistors, semiconductor temperature sensor, thermocouple, resonant circuit-based temperature sensor or the like. The second temperature sensor 26 is a contactlessly measuring temperature sensor, for example a pyrometer, volometer or thermopile, which measures the temperature by detecting the infrared radiation emitted by the measured object.

According to a modification (not shown), a tube may be arranged in the area of the measurement window 22 which also surrounds the second temperature sensor 26 and on the one hand concentrates or guides the infrared radiation emitted by the component carrier 12 and to be detected, while at the same time keeping external radiation that might falsify the temperature measurement away from the second temperature sensor 26.

Fig. 2 shows a soldering device 110 according to a further example, which is designed similarly to the soldering device 10 from Fig. 1. The soldering device 110 comprises several component carriers 12, three in the present example, wherein a separately controllable induction device 20 is associated with each component carrier 12. The distances of the induction devices 20 to the component carriers 12 are individually adjustable. All three component carriers 12 are arranged on a common conveying frame 14. The associated temperature sensors 24, 26 are arranged similarly to the example from Fig. 1.

The components of the soldering device 110 are located in a process chamber 28, which provides a preferably settable process atmosphere for the soldering process. The process chamber 28 may be temperature-regulated, evacuated and/or subjected to pressure or also flooded with different process gases. The pressure and/or the temperature of this process atmosphere may be set to preset values and in particular also altered. The first and second temperature sensors 24, 26 are arranged in or on the process chamber 28. In particular, the second temperature sensor 28 is arranged outside the process chamber and observes the second temperature point through an optical vision window of the process chamber wall.

Fig. 3 shows a soldering device 210 according to a further example, which in principle represents an inversion of the soldering device 110 from Fig. 2 on a horizontal axis. Unlike in the example in Figs. 1 and 2, the first temperature sensors 24 are in thermal contact not with the components 18, but with the undersides of the component carriers 12 as the first temperature point. The second temperature sensors 26 in turn do not measure the temperature of the component carrier 12, but can directly record the temperatures of the components 16 and/or 18 arranged above the component carrier 12 as the second temperature point.

All three examples show the devices configured for performance of the method in accordance with the invention as soldering devices 10, 110, 210. It goes without saying that the arrangement of the temperature sensors 24, 26 described here by way of example may also be provided alternatively for correspondingly designed sintering devices. With sintering devices of this type, additional tools are as a rule provided which may exert the press forces onto the components to be connected in order to manufacture a sintering device. These tools may if necessary have suitable measurement openings through which accesses are provided for the contactless or contact-based temperature measurement required for temperature measurement at the components or component parts of the sintering device.

It also goes without saying that the soldering devices 10, 110, 210 may also have the required tools that might be needed for applying the press force to the components 16, 18. For reasons of clarity, they are not shown in the present examples.

The following now describes in simplified manner a method in accordance with the invention for temperature regulation of components to make soldered or sintered joints between the components 16, 18. This method may be performed by means of the soldering devices 10, 110, 210 according to Figs. 1 to 3, for example in a control unit (not shown), which may be connected to the temperature sensors 24, 26 and to the induction device(s) 20 as heat sources. With the aid of a control unit of this type, it is in particular possible to control the heat output generated by the heat sources 20 in order to heat the components 16, 18 up to a required temperature and also to cool them down again by reducing or shutting off the heat output.

While the first temperature sensor 24 can determine the component temperature or component part temperature at the first temperature point very precisely due to its contact-based mode of operation, the component temperature or component part temperature at the second temperature point, determined by the second contactlessly operating temperature sensor 26, is subject to a systematic measurement error. One example for a contactlessly operating temperature sensor of this type is a pyrometer. This determines the radiation power P emitted by a measured body of which the temperature is to be determined. For technical reasons, only a defined wavelength range within the infrared range is as a rule taken into account here. According to the Stefan-Boltzmann law, the following applies for the total radiation power P of a real body:

$$P = \varepsilon \cdot \sigma \cdot A \cdot T^4, \quad (1)$$

where ε is the emissivity, σ the Stefan-Boltzmann constant ($\sigma = 5.6704 \cdot 10^{-8} \text{ Wm}^{-2}\text{K}^{-4}$), A the area (in m^2) and T the temperature (in K). The emissivity ε thus represents the heat radiation capacity of the measured object and depends both on the material and on the surface quality of the measured object. The second temperature is determined preferably with small wavelengths. The measuring wavelengths of a pyrometer are preferably no more than $5 \mu\text{m}$, particularly preferably no more than $2 \mu\text{m}$, in order to limit the effect of imprecisely determined emissivities ε on the measuring accuracy.

Since the emissivity ε of the measured object, i.e. of a component or of a component part of the soldering or sintering device, is frequently not known exactly or is also subject to local variations, the measured second temperature may have a systematic measurement error. For that reason, a calibrated second temperature is determined on the basis of the measured second temperature, wherein the measured first temperature is used as the calibration variable. To rule out here that the actual temperature at the place of the first temperature point where the first temperature is measured differs from the actual temperature at the place where the second temperature of the second temperature point is measured, the temperatures of the components 16, 18 or of the component parts of the soldering device 10, 110, 210 in thermal contact with the components should if possible be in balance, i.e. there should no longer be any temperature gradients between the different places of measurement of the first and second temperature points. This can be achieved for example in that the heat output of the heat source is kept constant for a certain

equalization time or is regulated to a constant temperature, and only then are the corresponding measured temperature values determined.

The calibrated second temperature may be determined for example on the basis of a calibration function which was determined as part of a calibration step. The determination of such a calibration function is described in more detail in the following.

One advantage of the method in accordance with the invention is that the measurement of the first temperature conducted at the first temperature point using a temperature sensor in thermal contact with a component or a device component, and therefore slow to respond but delivering a very precise measured value, is combined in suitable manner with the measurement of the second temperature, which is conducted by a contactlessly operating temperature sensor at the second temperature point, and therefore fast to respond but delivering only imprecise measured values due to its dependence on the material. An optimum temperature progression at the components is achieved by this combination of the measured values for the first and the second temperatures. Besides that, a flexible and spaced arrangement of the first and second temperature sensors is possible.

Fig. 4 shows exemplary curves over time for the first temperature (T1) and for the second temperature (T2), wherein the absolute value of the time scale is arbitrary. The temperatures T1, T2 were measured on opposite sides of a component consisting of copper and having a thickness of 5 mm. A heat source 20 is here arranged on the same side as the temperature sensor 26 recording the second temperature T2, while the temperature sensor 24 recording the first temperature T1 is arranged on that side of the component facing away from the heat source 20 (cf. the arrangements in Figs. 1 and 2).

While a maximum value of the second temperature T2 is around $t = 48$ sec, the first temperature T1 reaches a plateau at around $t = 55$ sec, i.e. the first temperature T1 remains approximately constant after this time. The time difference of 7 sec between reaching the maximum for the second temperature T2 and reaching the plateau of the first temperature T1 is based on the latency time due to heat transmission between the two sides of the component.

Furthermore, it may be discerned in Fig. 4 that the first temperature T1 has a substantially more slowly responding curve, hence with reduced fluctuations, than the second

temperature T2. Also, there is a temperature difference of approx. 20 to 25°C between the two temperatures T1, T2 due to the not yet performed calibration (Fig. 4 shows the measured second temperature T2).

With reference to Fig. 5, the performance of a calibration step is now explained in the following by way of example. To do so, a first temperature T1.1 is measured with contact, and a second temperature T2.1 contactlessly, at an exemplary component, the temperature of which is increased continually or in intervals, at a first point in time t1. At a second point in time t2, a first temperature T1.2 and a second temperature T2.2 are now measured.

Under the simplified assumption of a linear correlation between a measured second temperature T2 and a calibrated second temperature T2', said calibrated second temperature T2' can be determined according to the equation

$$T2' = k \cdot T2 + T_{\text{offset}}, \quad (2)$$

where k is a calibration factor and T_{offset} is a differential temperature at the point in time t1. The factor k can be determined from the temperatures measured at the points in time t1 and t2 in accordance with the following equation:

$$k = \frac{T1.2 - T1.1}{T2.2 - T2.1}. \quad (3)$$

The differential temperature T_{offset} can be determined from the measured temperature values in accordance with the following equation:

$$T_{\text{offset}} = T1.1 - (T2.1 \cdot k). \quad (4)$$

The temperature measurements for determining the calibration function are performed advantageously at points in time when the component does not have a temperature gradient, i.e. the component temperature is in each case kept constant for a suitable duration, for example 5 sec at a plateau, wherein the component temperature must of course be altered between the two points in time t1 and t2. It is also possible as a general principle to again perform a calibration at each preset point in time, for example at intervals of 10 sec.

Alternatively, the calibration step may also be performed as part of a specimen calibration step which is performed for a specimen component whose emission properties match those of the components later processed or those of device components in contact with the component, in order to save a calibration function. Recourse to this calibration function may be had later, during performance of the actual process step, i.e. of the actual soldering or sintering operation, without the need to perform new calibrations during performance of the process step.

Instead of the calibration explained with reference to Fig. 5, the emissivity ε may also be directly determined. This may be achieved for example by first determining, at an ambient temperature of for example 20°, the first temperature $T_{1.1}$ with contact and the second temperature $T_{2.1}$ contactlessly, similarly to as described with reference to Fig. 5. The component used as the test object is then heated to a higher temperature, for example to between 150°C and 250°C, and the first temperature $T_{1.2}$ and the second temperature $T_{2.2}$ are again determined.

The emissivity ε can then be calculated in accordance with the following equation:

$$\varepsilon = \frac{T_{2.2}^4 - T_{2.1}^4}{T_{1.2}^4 - T_{1.1}^4}. \quad (5)$$

It was assumed here that $T_{2.2}^4$ is smaller than $T_{1.2}^4$. Otherwise the values would have to be changed around, such that the emissivity ε is ≤ 1 .

With reference to Fig. 6, two-stage control or cascade control of a heat source is now described, wherein the control variable for this heat source is described by a function $u_2(t)$. Two temperature sensors are arranged on a measured object, wherein a first temperature sensor in contact with the measured object generates the first temperature T_1 and a contactlessly measuring temperature sensor generates the second temperature T_2 . The curve of the first temperature T_1 is described by a function $y_{M1}(t)$, and the curve of the second temperature T_2 by a function $y_{M2}(t)$. A setpoint temperature function $w_1(t)$ acts as the input variable for control.

From the signals $w_1(t)$ and $y_{M1}(t)$, a difference function $e_1(t)$ is generated by obtaining the difference according to the equation

$$e1(t)=w1(t) - yM1(t) \quad (6)$$

and passed to the master controller R1. The master controller R1 may for example be designed as a PI (proportional-integral) controller, which generates a control function $u1(t)$ according to the equation

$$u1(t) = e1(t) * kp + ki * \int e1(t) dt \quad (7)$$

wherein kp , ki are respective amplification factors. By positive coupling with the setpoint temperature function $w1(t)$, a modified setpoint temperature function $w2(t)$ is determined from $u1(t)$ according to the equation

$$w2(t) = \text{Min}(u1(t), dTmax) + w1(t) \quad (8)$$

.

In the second control stage, the difference of the modified setpoint temperature function $w2(t)$ and the function $yM2(t)$ is obtained according to the equation

$$e2(t)= w2(t) - yM2(t) \quad (9)$$

in order to generate an input function $e2(t)$ for the slave controller R2. The slave controller R2 generates from this the control variable or control function $u2(t)$ for the heat source according to the equation

$$u2(t) = e2(t) * kp + ki * \int e2(t) dt, \quad (10)$$

where kp , ki are respective amplification factors.

It goes without saying that the specific embodiment of the cascade control is here purely by way of example and if necessary may also be modified in a suitable manner.

The output from the heat source is set in a suitable manner. Control is thus possible, for example when using an induction device 20 in accordance with Figs. 1 to 3 as the heat source, by a control unit of the induction device 20 and by means of adjustments to the

frequency, current and/or voltage. In addition, the distance of the induction device 20 may also be incorporated into the control. When an infrared heater or an ohmic heating device is used, the heating current can be controlled.

Due to the rapid reaction of the heat source or of that side of the components 16, 18 or of the component carrier 12 facing the induction device 20, the temperature curve of the component side facing the induction device 20 may be controlled according to a wide spectrum of functions, for example ramps, S-curves, quadratic function, e-function, holding phases or polynomials of a higher degree.

This behavior can be exploited in order to speed up heating of the components 16, 18. To do so, the temperature of the component side facing the induction device 20 may be briefly increased in order to increase the temperature difference between the two opposite sides of the components 16, 18.

Due to the variations in component quality, in particular of the component side facing the induction device 20, no absolutely precise temperature can be recorded with the contactlessly measuring second temperature sensor 26. This disadvantage is compensated for by measurement of the component side facing away from the induction device 20 by means of the first temperature sensor 24, since the temperature level is continuously adjusted by this value such that the required temperature can always be set at the components 16, 18.

Under certain circumstances, effects on the contacting first temperature sensor 24 may result from external effects, for example by gas flowing into the process chamber 28, thereby impairing the control operation. This can be addressed by a modification of the cascade control described in connection with Fig. 6. Here the control variable $u1(t)$ generated by the master controller R1 may, at a given point in time, for example the time of an intended gas input, be “frozen” at a suitable value $u1_{freeze}$, thereby permitting improved temperature control to be achieved. The modified setpoint temperature $w2(t)$ is therefore not generated on the basis of $u1(t)$ and of the setpoint temperature $w1(t)$, but on the basis of $u1_{freeze}$ and $w1(t)$.

Typical curves over time of the functions $w_1(t)$, $y_{M1}(t)$, $y_{M2}(t)$ and $u_2(t)$ are now described with reference to Figs. 7 and 8, wherein characteristic event points are identified in the diagrams using numbers.

As can be discerned in Fig. 7, drops in the first temperature T_1 which are caused for example by gas flowing into the process chamber occur at the event points 1 and 3. These temperature drops lead, in the case of cascade control without the previously described “freeze function”, to an excessive counter-reaction by the cascade control, which becomes evident from temperature peaks in the curve of the second temperature T_2 at the event points 2 and 4.

By “freezing” the control variable $u_1(t)$ generated by the master controller to the value $u_{1\text{freeze}}$ directly before the start of events which might result in short-duration temperature changes to the components, improved temperature control over the component temperatures may be achieved.

With reference to Fig. 8, characteristic events and operations, likewise identified with numbers, during performance of the method in accordance with the invention with the aid of the previously described cascade control are now explained. That section of the curve of the second temperature T_2 ($y_{M2}(t)$) numbered 1 characterizes the lower measurement range limit of a pyrometer. During this period, the control variable $u_2(t)$ has a constant curve, as indicated by number 2.

Control commences at an event point 3. At an event point 4, there is a strong overshoot of the second temperature T_2 , which does not however lead to an overshoot in the curve of temperature T_1 ($y_{M1}(t)$), see number 7.

Number 5 characterizes the difference between the uncalibrated second temperature T_2 , which is higher than the setpoint temperature identified by the function $w_1(t)$ due to the differing surface properties of the measured object or components.

At an event point 6, the first temperature T_1 reaches precisely the predetermined setpoint temperature, wherein the measurement error of the contactlessly measuring second temperature sensor 28 is compensated for by calibration as described above.

Reference numeral list

10, 110, 210	Soldering device
12	Component carrier, component part
14	Conveying frame
16, 18	Component
20	Induction device, heat source
22	Measurement window
24	First temperature sensor
26	Second temperature sensor
28	Process chamber
R1	Master controller
R2	Slave controller

CLAIMS

1. A method for temperature regulation of components (16, 18) for making a soldered or sintered joint between the components (16, 18), wherein at least one controllable heat source (20) is provided to supply thermal energy to be transferred to the components (16, 18), wherein a first temperature of a component (16, 18) or of component part (12) of a soldering or sintering device (10, 110, 210) in thermal contact with a component (16, 18) is measured at at least one first temperature point by means of at least one first temperature sensor (24) which is in thermal contact with the component (16, 18) or with the component part (12), and a second temperature of a component (16, 18) or of a component part (12) of a soldering or sintering device (10, 110, 210) in thermal contact with a component (16, 18) is contactlessly measured by means of at least one second temperature sensor (26) at at least one second temperature point, wherein the first temperature point is spatially distant from the second temperature point such that a temperature gradient between the first and second temperatures may be expected in the event of a temperature change, and wherein the measured second temperature is calibrated on the basis of the measured first temperature in order to determine a calibrated second temperature, and wherein the heat source (20) is controlled at least on the basis of the calibrated second temperature.
2. The method according to claim 1, **characterized in** that the method is performed in a settable process atmosphere, wherein setting of the process atmosphere comprises at least the setting of a material composition, of a pressure and/or of a temperature of the process atmosphere.
3. The method according to claim 1 or 2, **characterized in** that the first temperature sensor (24) is selected from a group comprising at least NTC resistors, PTC resistors, semiconductor temperature sensors, thermocouples and resonant circuit-based temperature sensors, and/or that the second temperature sensor (26) is a sensor configured for detection of heat radiation and preferably selected from a group comprising at least pyrometers, bolometers and thermopiles.

4. The method according to any of the preceding claims, **characterized in** that the at least one heat source (20) is configured for contact-based or contactless heat transfer to the components (16, 18) or to the one or more of the component parts (12) mentioned and preferably selected from a group comprising generators of electric, magnetic or electromagnetic fields, preferably heating plates, induction heating elements or infrared radiators, which are couplable at least thermally, inductively or capacitively to the components (16, 18) or to the component part(s) (12) mentioned.
5. The method according to any of the preceding claims, **characterized in** that the heat source (20) is controlled in a process step comprising the making of the soldered or sintered joint, and the calibrated temperature is determined in at least one calibration step preceding the process step, wherein the calibration step comprises the generation and storage of a respective calibration function, on the basis of which the calibrated second temperature is determinable from a measured second temperature.
6. The method according to claim 5, **characterized in** that the calibration step is performed prior to each performance of a process step, wherein control of the heat source (20) is performed in the process step on the basis of the previously determined calibration function.
7. The method according to claim 5 or 6, **characterized in** that the calibration step is additionally also performed once or more during the process step, preferably at defined points in time or at points in time where the temperature of the components (16, 18) does not substantially change.
8. The method according to any of claims 5 to 7, **characterized in** that prior to performance of a process step, a calibration function matching the components (16, 18) to be processed is selected from a plurality of calibration functions stored in component-specific or component part-specific manner, wherein control of the heat source (20) in the process step is performed on the basis of the selected calibration function.
9. The method according to any of claims 5 to 8, **characterized in** that the calibration function is a linear function or a polynomial function, preferably of the fourth degree.

10. The method according to any of the preceding claims, **characterized in** that control of the heat source (20) is achieved in a two-stage method, wherein a modified setpoint temperature is determined in a first stage on the basis of the measured first temperature and of a preset setpoint temperature, and wherein an output from the heat source (20) is controlled in a second stage on the basis of the measured or calibrated second temperature and of the modified setpoint temperature.
11. The method according to any of the preceding claims, **characterized in** that the components (16, 18) to be connected are arranged in a main extent plane, wherein the first temperature sensor (24) is arranged on the one side of the main extent plane and the heat source (20) and the second temperature sensor (26) on the other side of the main extent plane, or wherein the first and second temperature sensors (24, 26) are arranged on the one side of the main extent plane and the heat source (20) on the other side of the main extent plane, or wherein the first and second temperature sensors (24, 26) and the heat source (20) are arranged on the same side of the main extent plane.
12. A soldering or sintering device (10, 110, 210) for making a soldered or sintered joint between components (16, 18), with at least one controllable heat source (20) which is configured to supply thermal energy to be transferred to the components (16, 18) at at least one first temperature point with at least one first temperature sensor (24) which is thermally contactable to a component (16, 18) or to a component part (12) of the soldering or sintering device (10, 110, 210) thermally contactable to a component (16, 18) and configured to measure a first temperature of the component (16, 18) or of the component part (12) mentioned, and an at least one second temperature point with a second temperature sensor (26) which is configured to measure contactlessly a second temperature of a component (16, 18) or of a component part (12) of the soldering or sintering device (10, 110, 210) thermally contactable to a component (16, 18), wherein the first temperature point is spatially distant from the second temperature point such that a temperature gradient between the first and second temperatures may be expected in the event of a temperature change, and with a control unit which is connected to the heat source (20) and to the first and second temperature sensors (24, 26) and is configured to perform the method according to any of the preceding claims.

13. The soldering or sintering device (10, 110, 210) according to claim 12, **characterized in** that the heat source (20) has a measurement window (22) which allows infrared radiation emitted by the components (16, 18) or by the component part(s) (12) mentioned of the soldering or sintering device (10, 110, 210) to pass in the direction of the second temperature sensor (26).
14. The soldering or sintering device (10, 110, 210) according to claim 13, **characterized in** that a tube facing at least in the direction of the second temperature sensor (26) is arranged in the measurement window and is configured to guide infrared radiation emitted by the components (16, 18) or by the component part(s) (12) mentioned of the soldering or sintering device (10, 110, 210) in the direction of the second temperature sensor (26) and preferably to shield the second temperature sensor (26) from infrared radiation which was not emitted by the components (16, 18) or by the component part(s) (12) mentioned.
15. The soldering or sintering device (10, 110, 210) according to any of claims 12 to 14, **characterized in** that the components (16, 18), the at least one heat source (20), the at least first temperature sensor (24) and the at least second temperature sensor (26) are arranged in or on a gas-tight process chamber (28) with a settable process atmosphere, in particular a vacuum, wherein the second temperature sensor (24) is preferably arranged on a side of the heat source (20) facing away from the components (16, 18).