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(54) **ADJUSTING A COOKING CYCLE ACCORDING TO THERMAL ATTRIBUTES OF COOKWARE ITEMS**

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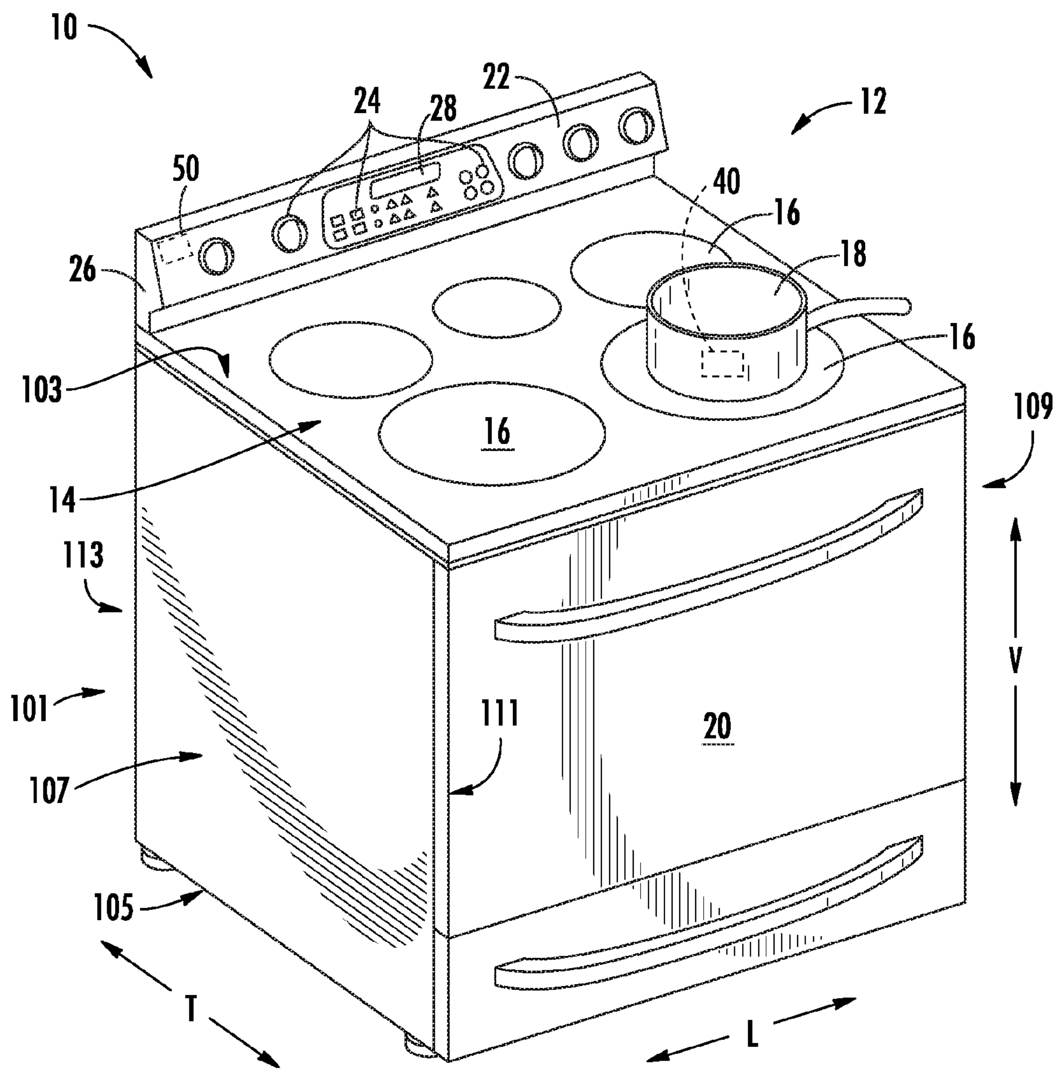
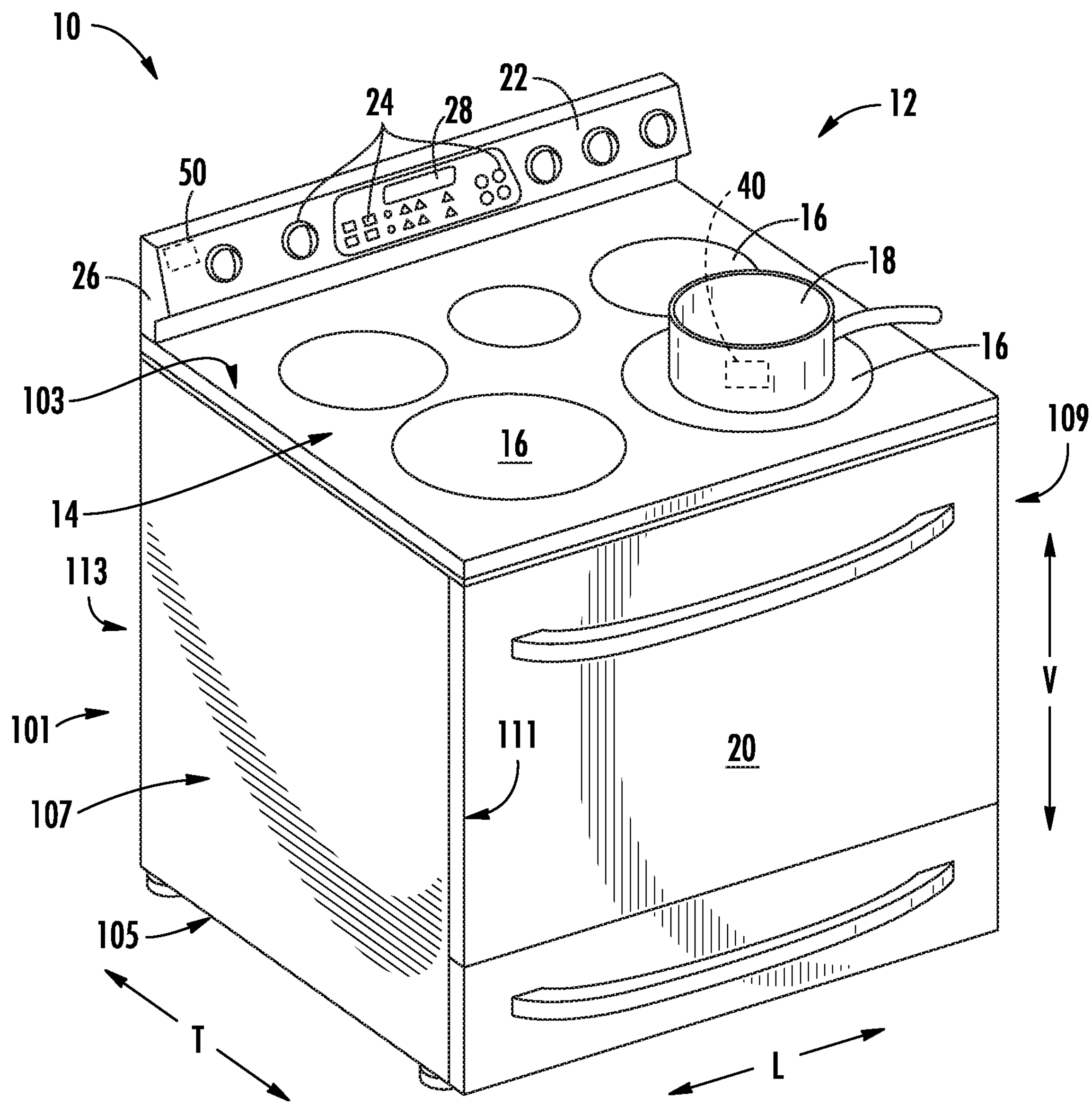
(57) **ABSTRACT**

A cooking appliance includes at least one heating element and a temperature sensor. A method of operating a cooking appliance includes determining a temperature setpoint for a heating operation of a cookware item; determining a power level for the at least one heating element based on the determined temperature setpoint; directing the at least one heating element over a thermal analysis phase according to the determined power level; determining a temperature rate of change at the temperature sensor at a conclusion of the thermal analysis phase; determining one or more parameters for a feedback controlled cooking phase according to the determined temperature rate of change at the temperature sensor, the one or more parameters comprising at least one controller gain value; and directing the at least one heating element according to the one or more determined parameters for a duration of the feedback controlled cooking phase.




10
24
28
22
12
50
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L

FIG. 1

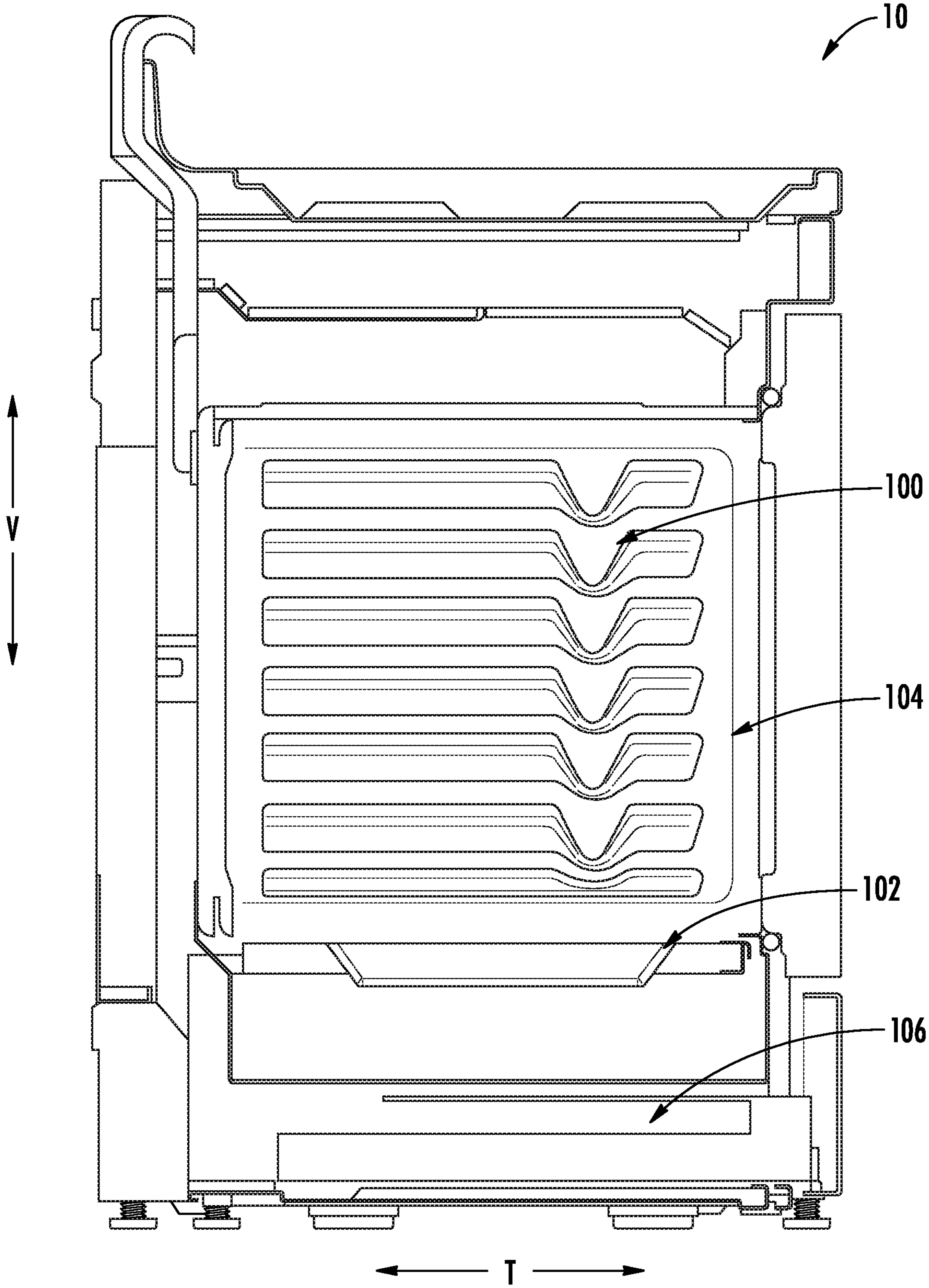

FIG. 2

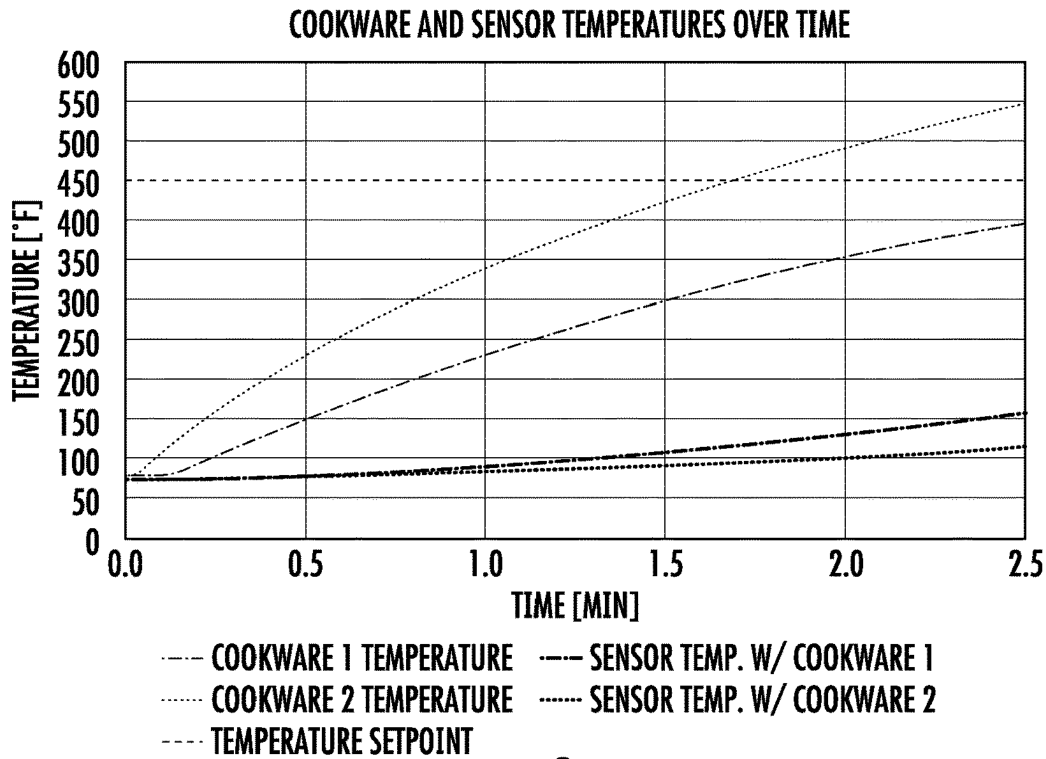
COOKWARE AND SENSOR TEMPERATURES OVER TIME
TEMPERATURE [°F]
600
550
500
450
400
350
300
250
200
150
100
50
0
0.0
0.5
1.0
1.5
2.0
2.5
TIME [MIN]
COOKWARE 1 TEMPERATURE
COOKWARE 2 TEMPERATURE
TEMPERATURE SETPOINT
SENSOR TEMP. W/ COOKWARE 1
SENSOR TEMP. W/ COOKWARE 2

FIG. 3

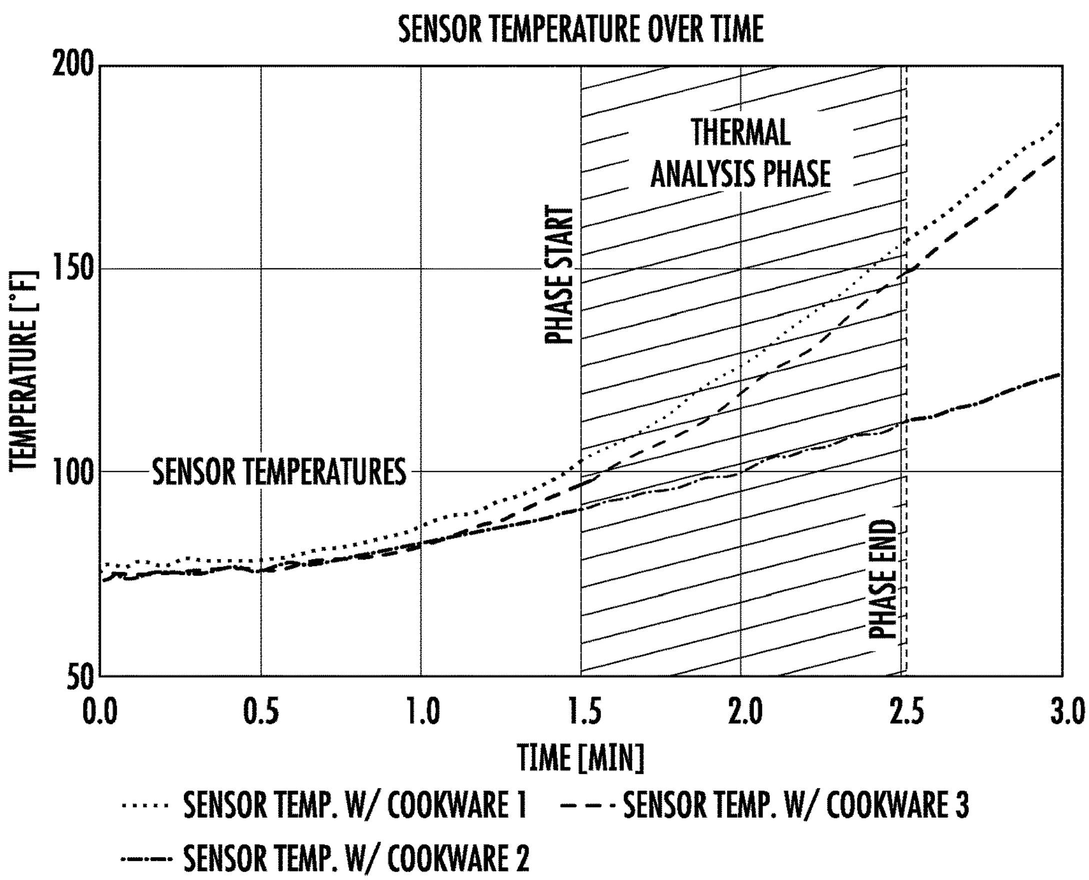
SENSOR TEMPERATURE OVER TIME
TEMPERATURE [°F]
200
150
100
50
THERMAL
ANALYSIS PHASE
PHASE START
PHASE END
SENSOR TEMPERATURES
0.0
0.5
1.0
1.5
2.0
2.5
3.0
TIME [MIN]
SENSOR TEMP. W/ COOKWARE 1
SENSOR TEMP. W/ COOKWARE 3
SENSOR TEMP. W/ COOKWARE 2

FIG. 4

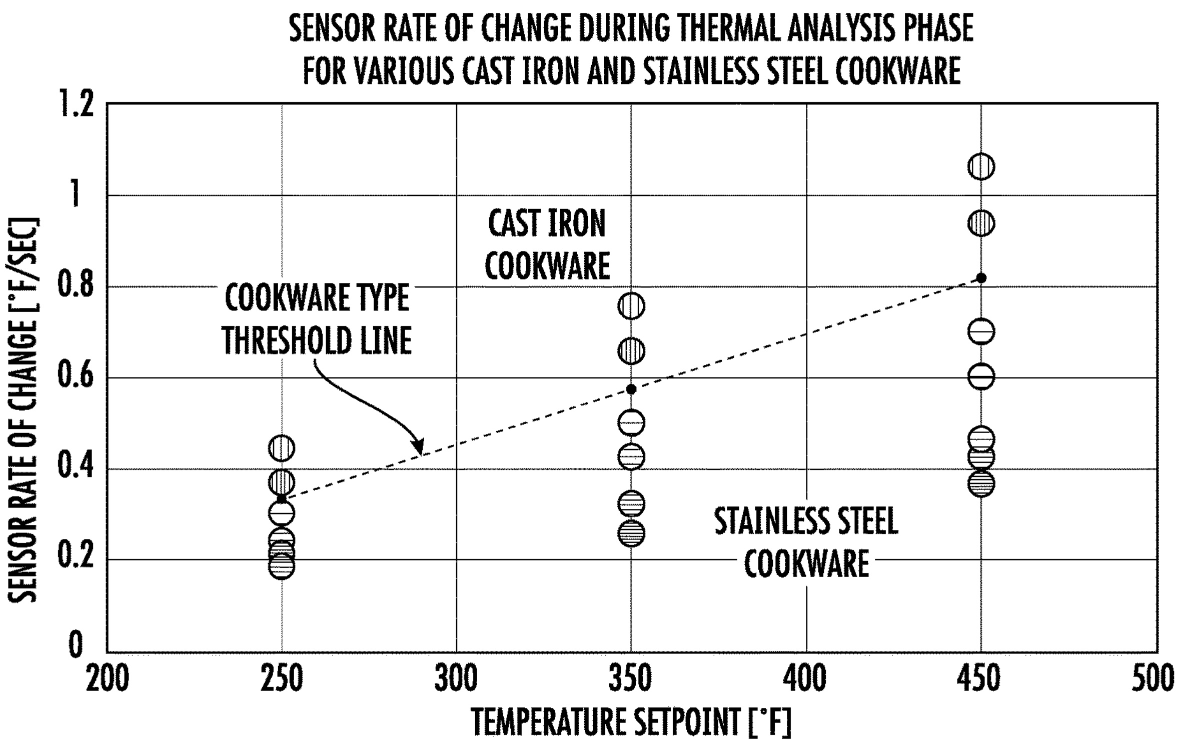

FIG. 5

TEMPERATURE SETPOINT [°F]	THRESHOLD RATE OF CHANGE [°F/SEC]
250	0.335
350	0.575
450	0.815

FIG. 6

	250°F TEMPERATURE SETPOINT		450°F TEMPERATURE SETPOINT	
COEFFICIENT	COEFFICIENT VALUE STAINLESS STEEL	COEFFICIENT VALUE CAST IRON	COEFFICIENT VALUE STAINLESS STEEL	COEFFICIENT VALUE CAST IRON
a_p	0.0124	0.0131	0.0095	0.0103
b_p	0.3438	0.4202	0.2645	0.3174
a_i	0.0000451	0.0000578	0.0000357	0.0000458
b_i	0.0002674	0.0003442	0.0002116	0.0002645
a_d	0.836	0.689	1.262	1.037
b_d	8.3152	7.2894	12.5163	10.9735

FIG. 7

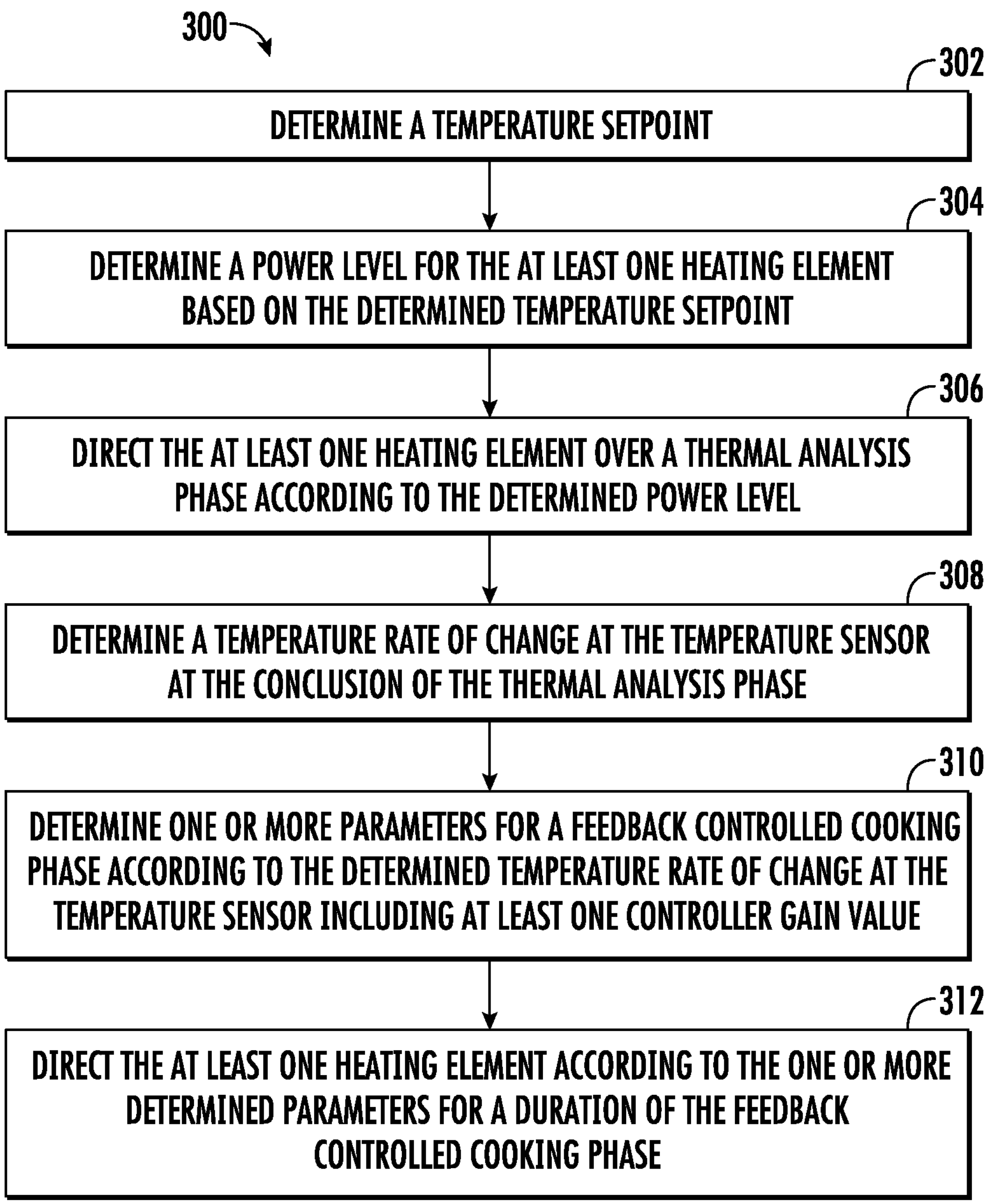
300
302
DETERMINE A TEMPERATURE SETPOINT
304
DETERMINE A POWER LEVEL FOR THE AT LEAST ONE HEATING ELEMENT BASED ON THE DETERMINED TEMPERATURE SETPOINT
306
DIRECT THE AT LEAST ONE HEATING ELEMENT OVER A THERMAL ANALYSIS PHASE ACCORDING TO THE DETERMINED POWER LEVEL
308
DETERMINE A TEMPERATURE RATE OF CHANGE AT THE TEMPERATURE SENSOR AT THE CONCLUSION OF THE THERMAL ANALYSIS PHASE
310
DETERMINE ONE OR MORE PARAMETERS FOR A FEEDBACK CONTROLLED COOKING PHASE ACCORDING TO THE DETERMINED TEMPERATURE RATE OF CHANGE AT THE TEMPERATURE SENSOR INCLUDING AT LEAST ONE CONTROLLER GAIN VALUE
312
DIRECT THE AT LEAST ONE HEATING ELEMENT ACCORDING TO THE ONE OR MORE DETERMINED PARAMETERS FOR A DURATION OF THE FEEDBACK CONTROLLED COOKING PHASE

FIG. 8

ADJUSTING A COOKING CYCLE ACCORDING TO THERMAL ATTRIBUTES OF COOKWARE ITEMS

FIELD OF THE INVENTION

[0001] The present subject matter relates generally to cooking appliances, and more particularly to methods of operating cooking appliances according to thermal behaviors of cookware items.

BACKGROUND OF THE INVENTION

[0002] Cooking appliances generally have one or more heating elements configured for heating a cookware item. The cookware item, e.g., a pot or a pan, may be positioned on or near the one or more heating elements and food products (including, e.g., food solids, liquid, or water) may be placed inside the cookware item for cooking. A controller may selectively energize the heating element(s) to provide thermal energy to the cookware item and the food products placed therein. Alternatively, certain cooking appliances, often referred to as induction cooktops, provide energy in the form of an alternating magnetic field which causes the cookware item to generate heat. In both types of appliances, a controller selectively energizes either the heating element (s) or a magnetic coil to heat the food products until they are properly cooked.

[0003] Cookware items may exhibit different thermal properties or behaviors. For instance, some cookware items may have slower heat transfer rates, retain heat more easily, or dissipate heat more easily. For cooking appliances that are capable of performing feedback controlled heating operations, one or more algorithms may be used to incorporate certain feedback information (e.g., temperature change, temperature rate of change, etc.) over a heating period to intelligently control a power level of the heating element(s). However, when cookware items exhibit different properties, the single feedback control algorithm results in undesirable heating behaviors, such as excessive temperature overshoots, long heat rise times, and the like.

[0004] Accordingly, a cooking appliance and method of operating a cooking appliance that obviates one or more of the above-mentioned drawbacks would be desirable. In particular, a cooking appliance capable of adjusting one or more parameters of a heating operation would be useful.

BRIEF DESCRIPTION OF THE INVENTION

[0005] Aspects and advantages of the invention will be set forth in part in the following description, or may be obvious from the description, or may be learned through practice of the invention.

[0006] In one exemplary aspect of the present disclosure, a cooking appliance is provided. The cooking appliance may include at least one heating element to selectively supply heat to a cookware item; a temperature sensor configured to selectively monitor a temperature of the cookware item; and a controller operably connected with the at least one heating element and the temperature sensor, the controller configured to perform a heating operation. The heating operation may include determining a temperature setpoint; determining a power level for the at least one heating element based on the determined temperature setpoint; directing the at least one heating element over a thermal analysis phase according to the determined power level; determining a temperature rate of change at the temperature sensor at a conclusion of the thermal analysis phase; determining one or more parameters for a feedback controlled cooking phase according to the determined temperature rate of change at the temperature sensor, the one or more parameters including at least one controller gain value; and directing the at least one heating element according to the one or more determined parameters for a duration of the feedback controlled cooking phase.

[0007] In another exemplary aspect of the present disclosure, a method of operating a cooking appliance is provided. The cooking appliance may include at least one heating element and a temperature sensor. The method may include determining a temperature setpoint for a heating operation of a cookware item; determining a power level for the at least one heating element based on the determined temperature setpoint; directing the at least one heating element over a thermal analysis phase according to the determined power level; determining a temperature rate of change at the temperature sensor at a conclusion of the thermal analysis phase; determining one or more parameters for a feedback controlled cooking phase according to the determined temperature rate of change at the temperature sensor, the one or more parameters including at least one controller gain value; and directing the at least one heating element according to the one or more determined parameters for a duration of the feedback controlled cooking phase.

[0008] These and other features, aspects and advantages of the present invention will become better understood with reference to the following description and appended claims. The accompanying drawings, which are incorporated in and constitute a part of this specification, illustrate embodiments of the invention and, together with the description, serve to explain the principles of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] A full and enabling disclosure of the present invention, including the best mode thereof, directed to one of ordinary skill in the art, is set forth in the specification, which makes reference to the appended figures.

[0010] FIG. **1** provides a perspective view of an oven range according to exemplary embodiments of the present disclosure.

[0011] FIG. **2** provides a side cut-away view of the exemplary oven range of FIG. **1**.

[0012] FIG. **3** provides a graph illustrating a comparison of cookware temperatures and sensor temperatures over time according to exemplary embodiments of the present disclosure.

[0013] FIG. **4** provides a graph illustrating multiple sensor temperatures over a thermal analysis phase of an exemplary heating operation.

[0014] FIG. **5** provides a graph illustrating multiple temperature rates of change of different cookware items at different setpoints of exemplary heating operations.

[0015] FIG. **6** provides a table illustrating a plurality of threshold temperature rates of change for a plurality of temperature setpoints according to exemplary embodiments of the present disclosure.

[0016] FIG. **7** provides a table illustrating a plurality of coefficient values for a plurality of temperature setpoints and cookware item materials according to exemplary embodiments of the present disclosure.

[0017] FIG. **8** provides a flow chart illustrating a method of operating a cooking appliance according to exemplary embodiments of the present disclosure.

[0018] Repeat use of reference characters in the present specification and drawings is intended to represent the same or analogous features or elements of the present invention.

DETAILED DESCRIPTION

[0019] Reference now will be made in detail to embodiments of the invention, one or more examples of which are illustrated in the drawings. Each example is provided by way of explanation of the invention, not limitation of the invention. In fact, it will be apparent to those skilled in the art that various modifications and variations can be made in the present invention without departing from the scope of the invention. For instance, features illustrated or described as part of one embodiment can be used with another embodiment to yield a still further embodiment. Thus, it is intended that the present invention covers such modifications and variations as come within the scope of the appended claims and their equivalents.

[0020] As used herein, the terms "first," "second," and "third" may be used interchangeably to distinguish one component from another and are not intended to signify location or importance of the individual components. The terms "includes" and "including" are intended to be inclusive in a manner similar to the term "comprising." Similarly, the term "or" is generally intended to be inclusive (i.e., "A or B" is intended to mean "A or B or both"). In addition, here and throughout the specification and claims, range limitations may be combined and/or interchanged. Such ranges are identified and include all the sub-ranges contained therein unless context or language indicates otherwise. For example, all ranges disclosed herein are inclusive of the endpoints, and the endpoints are independently combinable with each other. The singular forms "a," "an," and "the" include plural references unless the context clearly dictates otherwise.

[0021] Approximating language, as used herein throughout the specification and claims, may be applied to modify any quantitative representation that could permissibly vary without resulting in a change in the basic function to which it is related. Accordingly, a value modified by a term or terms, such as "generally," "about," "approximately," and "substantially," are not to be limited to the precise value specified. In at least some instances, the approximating language may correspond to the precision of an instrument for measuring the value, or the precision of the methods or machines for constructing or manufacturing the components and/or systems. For example, the approximating language may refer to being within a 10 percent margin, i.e., including values within ten percent greater or less than the stated value. In this regard, for example, when used in the context of an angle or direction, such terms include within ten degrees greater or less than the stated angle or direction, e.g., "generally vertical" includes forming an angle of up to ten degrees in any direction, e.g., clockwise or counterclockwise, with the vertical direction V.

[0022] The word "exemplary" is used herein to mean "serving as an example, instance, or illustration." In addition, references to "an embodiment" or "one embodiment" does not necessarily refer to the same embodiment, although it may. Any implementation described herein as "exemplary" or "an embodiment" is not necessarily to be construed as preferred or advantageous over other implementations. Moreover, each example is provided by way of explanation of the invention, not limitation of the invention. In fact, it will be apparent to those skilled in the art that various modifications and variations can be made in the present invention without departing from the scope of the invention. For instance, features illustrated or described as part of one embodiment can be used with another embodiment to yield a still further embodiment. Thus, it is intended that the present invention covers such modifications and variations as come within the scope of the appended claims and their equivalents.

[0023] FIG. **1** provides a perspective view of a cooking appliance, or oven range **10**, including a cooktop **12**, and FIG. **2** provides a side cut-away view of the cooking appliance **10**. Cooking appliance **10** is provided by way of example only and is not intended to limit the present subject matter to the arrangement shown in FIGS. **1** and **2**. Thus, the present subject matter may be used with other range **10** and/or cooktop **12** configurations, e.g., double oven range appliances. As illustrated, cooking appliance **10** generally defines a vertical direction V, a lateral direction L, and a transverse direction T, each of which is mutually perpendicular, such that an orthogonal coordinate system is generally defined. Cooking appliance **10** may include a cabinet **101** that extends between a top **103** and a bottom **105** along the vertical direction V, between a left side **107** and a right side **109** along the lateral direction, and between a front **111** and a rear **113** along the transverse direction T.

[0024] A cooking surface **14** of cooktop **12** may include a plurality of heating elements **16**. For the embodiment depicted, cooktop **12** includes five heating elements **16** spaced along cooking surface **14**. Heating elements **16** may be electric heating elements and are positioned at, e.g., on or proximate to, the cooking surface **14**. In certain exemplary embodiments, cooktop **12** is a radiant cooktop with resistive heating elements or coils mounted below cooking surface **14**. However, in other embodiments, the cooktop appliance **12** includes other suitable shape, configuration, and/or number of heating elements **16**, for example, cooktop **12** may be an open coil cooktop with heating elements **16** positioned on or above surface **14**. Additionally or alternatively, in other embodiments, cooktop **12** may include any other suitable type of heating element **16**, such as an induction heating element. Each of the heating elements **16** may be the same type of heating element **16**, or cooktop **12** may include a combination of different types of heating elements **16**.

[0025] As mentioned, heating element **16** may be an induction style heating element. Thus, as would be understood by those skilled in the art, appliance **10** may supply a current to heating element **16** (e.g., such as a Lenz coil). As such, current may pass through heating element **16** to generate a magnetic field. The magnetic field may be a high frequency circulating magnetic field. The magnetic field may be directed towards and through cooktop appliance **12** to a cookware item (e.g., cookware item **18**, described below). In particular, when the magnetic field penetrates cookware item **18**, the magnetic field induces a circulating electrical current within cookware item **18**. The material properties of cookware item **18** may restrict a flow of the induced electrical current and convert the induced electrical current into heat within cookware item **18**. As cookware item **18** heats up, contents of cookware item **18** contained therein heat up as well. In such a manner, the induction heating element can cook the contents of cookware item **18**.

[0026] As shown in FIG. **1**, a cooking utensil (or cookware item) **18**, such as a pot, pan, or the like, may be placed on a heating element **16** to heat cookware item **18** and cook or heat food items placed within cookware item **18**. Cooking appliance **10** may also include a door **20** that permits access to a cooking chamber **104** of oven range **10**, e.g., for cooking or baking of food items therein. A control panel **22** having controls **24** may permit a user to make selections for cooking of food items. Although shown on a backsplash or back panel **26** of oven range **10**, control panel **22** may be positioned in any suitable location.

[0027] Controls **24** may include buttons, knobs, and the like, as well as combinations thereof, and/or controls **24** may be implemented on a remote user interface device such as a smartphone. As an example, a user may manipulate one or more controls **24** to select a temperature and/or a heat or power output for each heating element **16** and the cooking chamber **104**. The selected temperature or heat output of heating element **16** affects the heat transferred to cookware item **18** placed on heating element **16**. A display **28** may be provided (e.g., on or in control panel **22**). Display **28** may display information regarding cooking operations or inputs from a user regarding the cooking operation. Display **28** may be any suitable display capable of providing visual feedback, such as a liquid crystal display (LCD), a light emitting diode (LED) display, a segmented display, or the like. Additionally or alternatively, display **28** may be a touch display capable of receiving touch inputs from a user.

[0028] Cooktop appliance **12** may further include or be in operative communication with a processing device or a controller **50** that may be generally configured to facilitate appliance operation. In this regard, control panel **22**, controls **24**, and display **28** may be in communication with controller **50** such that controller **50** may receive control inputs from controls **24**, may display information using display **28**, and may otherwise regulate operation of cooking appliance **10**. For example, signals generated by controller **50** may operate cooking appliance **10**, including any or all system components, subsystems, or interconnected devices, in response to the position of controls **24** and other control commands. Control panel **22** and other components of appliance **10** may be in communication with controller **50** via, for example, one or more signal lines or shared communication busses. In this manner, Input/Output ("I/O") signals may be routed between controller **50** and various operational components of appliance **10**.

[0029] As used herein, the terms "processing device," "computing device," "controller," or the like may generally refer to any suitable processing device, such as a general or special purpose microprocessor, a microcontroller, an integrated circuit, an application specific integrated circuit (ASIC), a digital signal processor (DSP), a field-programmable gate array (FPGA), a logic device, one or more central processing units (CPUs), a graphics processing units (GPUs), processing units performing other specialized calculations, semiconductor devices, etc. In addition, these "controllers" are not necessarily restricted to a single element but may include any suitable number, type, and configuration of processing devices integrated in any suitable manner to facilitate appliance operation. Alternatively, controller **50** may be constructed without using a microprocessor, e.g., using a combination of discrete analog and/or digital logic circuitry (such as switches, amplifiers, integrators, comparators, flip-flops, AND/OR gates, and the like) to perform control functionality instead of relying upon software.

[0030] Controller **50** may include, or be associated with, one or more memory elements or non-transitory computer-readable storage mediums, such as RAM, ROM, EEPROM, EPROM, flash memory devices, magnetic disks, or other suitable memory devices (including combinations thereof). These memory devices may be a separate component from the processor or may be included onboard within the processor. In addition, these memory devices can store information and/or data accessible by the one or more processors, including instructions that can be executed by the one or more processors. It should be appreciated that the instructions can be software written in any suitable programming language or can be implemented in hardware. Additionally, or alternatively, the instructions can be executed logically and/or virtually using separate threads on one or more processors.

[0031] For example, controller **50** may be operable to execute programming instructions or micro-control code associated with an operating cycle of cooking appliance **10**. In this regard, the instructions may be software or any set of instructions that when executed by the processing device, cause the processing device to perform operations, such as running one or more software applications, displaying a user interface, receiving user input, processing user input, etc. Moreover, it should be noted that controller **50** as disclosed herein is capable of and may be operable to perform any methods, method steps, or portions of methods as disclosed herein. For example, in some embodiments, methods disclosed herein may be embodied in programming instructions stored in the memory and executed by controller **50**.

[0032] The memory devices may also store data that can be retrieved, manipulated, created, or stored by the one or more processors or portions of controller **50**. The data can include, for instance, data to facilitate performance of methods described herein. The data can be stored locally (e.g., on controller **50**) in one or more databases and/or may be split up so that the data is stored in multiple locations. In addition, or alternatively, the one or more database(s) can be connected to controller **50** through any suitable network(s), such as through a high bandwidth local area network (LAN) or wide area network (WAN). In this regard, for example, controller **50** may further include a communication module or interface that may be used to communicate with one or more other component(s) of appliance **10**, controller **50**, an external appliance controller, or any other suitable device, e.g., via any suitable communication lines or network(s) and using any suitable communication protocol. The communication interface can include any suitable components for interfacing with one or more network(s), including for example, transmitters, receivers, ports, controllers, antennas, or other suitable components.

[0033] Cooking appliance **10** may include a temperature sensor **40**. Temperature sensor **40** may be configured to selectively sense a temperature of a cookware item (e.g., cookware item **18**) as it is heated. For instance, temperature sensor **40** may be integrally formed with cooking appliance **10** (e.g., within cooktop **12**, within cooking chamber **104**, etc.). In some embodiments, temperature sensor **40** is operably connected to cooking appliance **10** (e.g., via a port or socket, via a remote connection, etc.). For one example, temperature sensor **40** is provided within cookware item **18**

and operably connected to controller **50** during a cooking operation. Temperature sensor **40** may monitor a temperature of cookware item **18** or a food item provided within cookware item **18**. Accordingly, temperature sensor **40** may deliver signals (e.g., voltage signals) representing the temperature of cookware item **18** to controller **50**. The signals may be sent according to a predetermined frequency (e.g., at predetermined time intervals). Thus, controller **50** may analyze a temperature or temperature change of cookware item **18**.

[0034] As used herein, "temperature sensor" or the equivalent is intended to refer to any suitable type of temperature measuring system or device positioned at any suitable location for measuring the desired temperature. Thus, for example, temperature sensor **40** may be any suitable type of temperature sensor, such as a thermistor, a thermocouple, a resistance temperature detector, a semiconductor-based integrated circuit temperature sensor, etc. In addition, temperature sensor **40** may be positioned at any suitable location and may output a signal, such as a voltage, to a controller that is proportional to or indicative of the temperature being measured. Although exemplary positioning of temperature sensors is described herein, it should be appreciated that appliance **10** may include any other suitable number, type, and position of temperature or other sensors according to alternative embodiments.

[0035] FIGS. **3** and **4** provide graphs illustrating temperature changes of different types of cookware over time and corresponding temperature changes of a temperature sensor (e.g., temperature sensor **40**) over time. As mentioned above, temperature sensor **40** may monitor the temperature of cookware item **18** over the course of the cooking or heating operation. The heating operation may include a thermal analysis period or phase (TAP). During the TAP, a thermal behavior of cookware item **18** may be determined (e.g., within controller **50**). The TAP may be predetermined within appliance **10** (e.g., during programming or manufacturing) according to empirical testing. For instance, the TAP may be defined between an initiation of the heating operation to between about 2 minutes and about 4 minutes. According to some embodiments, the TAP is between about 1 minute (e.g., 1 minute after the heating operation is initiated) to about 3 minutes (e.g., after the heating operation is initiated). Accordingly, the TAP may be between about 2 minutes and about 4 minutes in total length. During the TAP, temperature sensor **40** may continually send temperature signals to controller **50**.

[0036] The heating operation may include a cooking phase. The cooking phase may be a feedback controlled cooking phase. In detail, the cooking phase may intelligently adjust one or more parameters according to feedback with respect to cookware item **18**, a food being cooked, cooking appliance **10**, or the like. Temperature sensor **40** may continually send temperature signals to controller **50** which may then determine, for instance, an error value associated with the feedback controlled cooking phase. The error value may be a difference between a temperature setpoint and an actual observed temperature (e.g., via temperature sensor **40**). The error value may be substituted into a feedback equation to determine an adjustment to be made to a control variable. For instance, the control variable may be a power level of heating element **16**.

[0037] According to at least some embodiments, controller **50** includes a closed-loop feedback control algorithm. The closed-loop feedback control algorithm may be a proportional-integral-derivative (PID) algorithm or equation (e.g., equation or set of equations). In some embodiments, the algorithm may include a proportional algorithm, a proportional-integral algorithm, a proportional-derivative algorithm, or any suitable combination of terms. The PID controller may determine a proportional term (P), an integral term (I), and a derivative term (D). According to at least one embodiment, the PID algorithm is:

$$CV = P + I + D$$

[0038] where CV is a controlled variable (e.g., power input to heating element **16**), P is the proportional term, I is the integral term, and D is the derivative term. As can be seen, adding each of the P, I, and D terms generates a value for the power level of heating element **16**. Each of the P, I, and D terms may be found as follows:

$$P = K_p * e$$

$$I = I_{prev} + K_i * e * T_s$$

$$D = K_d * (e - e_{prev}) / T_s$$

[0039] where K_p is a proportional gain value, K_i is an integral gain value, K_d is a derivative gain value, e is an error value (e.g., a difference between a temperature setpoint and an observed temperature), T_s is a sampling time or sampling time rate (e.g., a rate at which a discrete system samples inputs), I_{prev} is a previous integral term (e.g., at the previous sampling event), and e_{prev} is a previous error value (e.g., at the previous sampling event). As noted above, however, in some instances any suitable combination of P, I, and D terms may be incorporated into the algorithm.

[0040] As seen in FIG. **3**, over time (e.g., throughout the TAP), the cookware item (e.g., cookware item **18**) and the temperature sensor (e.g., temperature sensor **40**) may receive heat at different rates. In detail, as mentioned above, cooktop appliance **12** may be an induction style cooktop appliance. Accordingly, heating element **16** may include one or more induction style energy generators. Because cooktop appliance **12** itself does not directly generate heat, a difference in temperature may be observed between cookware item **18** and temperature sensor **40**. For instance, in an embodiment where temperature sensor **40** is located within cooktop **12**, as cookware item **18** heats up, the heat from cookware item **18** is then emitted to temperature sensor **40** (e.g., through cooking surface **14**). Accordingly, cookware items with certain properties may heat up more quickly than temperature sensor **40** (e.g., as shown in FIG. **3**).

[0041] Referring now to FIG. **4**, a temperature change at temperature sensor **40** over the TAP is illustrated for various cookware items. As shown, temperature sensor **40** may exhibit different temperature changes over the TAP depending on which material is used in the specific cookware item **18**. For instance, a cookware item including or composed of cast iron may have a higher temperature rate of change (ROC) than a cookware item including or composed of stainless steel. It should be understood that the cookware items described or mentioned herein are provided by way of example only, and that any suitable or functional cookware item or items may be incorporated into the present disclosure.

[0042] As mentioned, temperature sensor **40** may continually monitor a temperature throughout the TAP. At the conclusion of the TAP, the temperature ROC may be calculated. For instance, the ROC may be determined as a change in temperature (e.g., delta T) over a change in time (e.g., delta t). Thus, a difference between the end temperature sensed at temperature sensor **40** (e.g., in degrees Fahrenheit) and the starting or initial temperature at temperature sensor **40** may be divided by the total length of the TAP (e.g., in seconds) to determine the ROC. From the determined ROC, certain properties of the cookware item being used may be inferred, retrieved, assumed, or calculated.

[0043] FIG. **5** provides a graph illustrating a temperature ROC for a plurality of cookware items at different temperature setpoints. As will be explained further below, the TAP may be performed at a variety of different temperature setpoints. At each setpoint, the temperature ROC may differ as the heat produced within cookware item **18** may be more intense or less intense. As mentioned above, a cookware item material composition may be inferred from the determined temperature ROC. As shown in FIG. **5**, a temperature ROC threshold may be defined. The temperature ROC threshold may be a threshold rate that can be used to differentiate the cookware item material types. For example, cookware items with temperature ROCs above the threshold may be determined to be cast iron cookware items. Additionally or alternatively, cookware items with temperature ROCs below the threshold may be determined to be stainless steel cookware items. Again, it should be understood that additional or alternative cookware item material types may be included or determined.

[0044] Moreover, variation may be present within each individual cookware item beyond the broad categorization of "above" or "below" the temperature ROC threshold. For instance, certain cast iron cookware items may exhibit slightly higher temperature ROCs than other cast iron cookware items, etc. Thus, the temperature ROC threshold may be determined according to an average of multiple different cookware items including similar material compositions. Additionally or alternatively, a plurality of cookware items of a first material composition (e.g., cast iron) may be tested to determine individual ROCs for each item. Similarly, a plurality of cookware items of a second material composition (e.g., stainless steel) may be tested to determine individual ROCs for each item. The temperature ROC threshold may then be positioned between the closest ROC of the first material item and the closest ROC of the second material item such that each first material item is on one side of the threshold while each second material item is on the opposite side of the threshold. As shown in FIG. **6**, for instance, the temperature ROC threshold may be tabulated according to different temperature setpoints. It should be understood that the temperature ROC threshold may be calculated, interpolated, extrapolated, or otherwise determined according to two or more predefined threshold values (e.g., between 250° F. and 350° F.). Accordingly, any suitable temperature setpoint may have a unique temperature ROC threshold value.

[0045] Returning to the equation described above, the gain values K_p, K_i, and K_d may be determined according to the determined temperature ROC. Accordingly, the controller terms (e.g., PID controller terms) may be dependent upon and vary according to a system response (e.g., such as determined by the temperature ROC). Coefficients may be determined for each of the gain values K_p, K_i, and K_d. For instance, a set of proportional coefficients, a set of integral coefficients, and a set of derivative coefficients may be determined. Together with the determined temperature ROC, the gain values K_p, K_i, and K_d may be calculated, for instance, using the following equations:

$$K_p = a_p * ROC + b_p$$

$$K_i = a_i * ROC + b_i$$

$$K_d = \frac{a_d}{ROC} + b_d$$

[0046] where K_p is the proportional gain, K_i is the integral gain, K_d is the derivative gain, ROC is the temperature rate of change, a_p and b_p are the set of proportional coefficients, a_i and b_i are the set of integral coefficients, and a_d and b_d are the set of derivative coefficients. As can be seen, the proportional gain and the integral gain are directly proportional to the temperature ROC while the derivative gain is inversely proportional to the temperature ROC. Accordingly, when a higher ROC is observed (e.g., at the temperature sensor), the cookware item may in turn respond more slowly to heating (e.g., as shown in FIG. **3**). As such, higher or more aggressive proportional and integral gain values (e.g., K_p and K_i) may be required to maintain the cookware item's steady state temperature value. Similarly, a lower or less aggressive derivative gain value (e.g., K_d) may assist in compensating for rapid sensor temperature changes (e.g., observed temperature changes at temperature sensor **40**).

[0047] Each of the set of proportional coefficients, the set of integral coefficients, and the set of derivative coefficients may vary according to the temperature ROC. For instance, each set of coefficients may be predetermined or predefined and stored within a lookup table. In some instances, a plurality of select coefficient values are provided for baseline temperature ROC values. Therefore, the coefficient values may be calculated (e.g., interpolated, extrapolated, etc.) from the plurality of select coefficients, for instance, when a temperature ROC lies between prestored temperature ROCs.

[0048] According to additional or alternative embodiments, predefined or preset ROCs may be incorporated into one or more equations to determine the required coefficients. For example, a lookup table may be stored (e.g., within appliance **10**) containing predetermined ROCs for a plurality of cookware items. The predetermined ROCs may include a first set of ROCs for a variety of cookware items having a composition of a first material (e.g., cast iron) and a second set of ROCs for a variety of cookware items having a composition of a second material (e.g., stainless steel). It should be acknowledged that additional ROCs may be incorporated, such as for additional material compositions apart from cast iron and stainless steel. In determining the ROC in order to implement the correct coefficients, an average ROC of the stored ROCs for the determined material type may be retrieved. For instance, upon determining that the material of the cookware item is the first material (e.g., cast iron), an average of all stored first material ROCs may be determined (or retrieved). The determined average

ROC may then be implemented into an equation to determine the required controller gains (e.g., K_p, K_i, and K_d).

[0049] As shown in FIG. 7, a table of coefficients is provided. According to some embodiments, each set of coefficients may further depend on a determined cookware item material type (e.g., cast iron, stainless steel, etc.). For instance, each of the set of proportional coefficients, the set of integral coefficients, and the set of derivative coefficients may be stored within a lookup table (e.g., provided within a memory of appliance **10**). As shown in FIG. 7, for example, the coefficient values are provided for each of a stainless steel cookware item and a cast iron cookware item. Moreover, in additional or alternative embodiments, coefficient values are provided for each of a 250° F. temperature setpoint and a 450° F. temperature setpoint. As mentioned above, coefficient values for different setpoints may be calculated (e.g., interpolated, extrapolated, etc.).

[0050] Now that the construction of cooking appliance **10** and a configuration of controller **50** according to exemplary embodiments have been presented, an exemplary method **300** of operating a cooking appliance will be described. Although the discussion below refers to the exemplary method **300** of operating cooking appliance **10**, one skilled in the art will appreciate that the exemplary method **300** is applicable to the operation of a variety of other cooking appliances. In exemplary embodiments, the various method steps as disclosed herein may be performed by controller **50** or a separate, dedicated controller. Additionally or alternatively, the various method steps may be performed in a different order, including additional steps or omitting certain steps according to specific embodiments.

[0051] At step **302**, method **300** may include determining a temperature setpoint. In detail, a user may communicate with the cooking appliance (e.g., cooking appliance **10**) a desire to initiate a cooking operation, a heating operation, or the like. For example, the cooking operation is a feedback controlled heating operation incorporating a PID algorithm to continually monitor the heating operation and perform adjustments as needed. The user may manually enter a temperature setpoint (e.g., a temperature at which the user desires to have the item cooked). Thus, using a user interface (e.g., control panel **22**), the user may enter a specific cooking temperature as the temperature setpoint (e.g., 250° F., 300° F., 350° F., etc.). In additional or alternative embodiments, the user may provide information regarding a specific food item to be cooked (e.g., eggs, meat, vegetables, etc.). For instance, the cooking appliance may include features for selecting predetermined food items from the user interface or the cooking appliance may include a remote connectivity (e.g., wireless fidelity [WiFi], Bluetooth®, etc.), through which the user may select a food item (e.g., via a remote device). Further still, the user may input a particular recipe to be cooked on or in the cooking appliance. The temperature setpoint may be stored within the cooking appliance (e.g., within a controller or a memory therein).

[0052] At step **304**, method **300** may include determining a power level for the at least one heating element based on the determined temperature setpoint. For instance, the cooking operation may include a preheating phase and a cooking phase following the preheating phase. The preheating phase may include the thermal analysis phase (TAP), discussed above, during which the cookware item may be analyzed according to one or more measured parameters (e.g., temperature response). The preheating phase may be instituted as a constant power phase (e.g., not feedback controlled). For instance, a constant power level may be applied to the at least one heating element during the preheating phase. The determined power level may be based at least in part on the temperature setpoint. Thus, a lower temperature setpoint may result in a lower determined power level for the preheating phase, while a higher temperature setpoint may result in a higher determined power level.

[0053] At step **306**, method **300** may include directing the at least one heating element over the thermal analysis phase (TAP) according to the determined power level. As mentioned, the TAP may be performed during the preheating phase (e.g., during the constant power or non-feedback controlled preheating phase). The TAP may be initiated at the determined power level. For instance, the heating element may be driven at a certain determined power percentage (e.g., 60%, 70%, 80%, etc.) over the TAP. The TAP may be initiated after a predetermined amount of time from the initiation of the heating operation. For instance, the TAP may be initiated between about 1 minute and about 3 minutes after the initiation of the heating operation. Additionally or alternatively, the TAP may be performed for a predetermined length of time. For example, the TAP may be performed for between about 1 minute and about 3 minutes. It should be noted that the time lengths stated herein are provided by way of example only, and that any suitable lengths of time may be incorporated. Over the course of the TAP, a temperature sensed at the temperature sensor (e.g., temperature sensor **40**) may be continually monitored, as will be explained.

[0054] At step **308**, method **300** may include determining a temperature rate of change (ROC) at the temperature sensor at the conclusion of the thermal analysis phase. In detail, method **300** may perform one or more calculations to determine a change in the sensed temperature at the temperature sensor over the length of the TAP. In some instances, the temperature at the temperature sensor is continually monitored throughout the TAP. However, additional or alternative embodiments may include recording an initial temperature at the initiation of the TAP and a final temperature at the conclusion, expiration, or end of the TAP. The initial temperature may then be subtracted from the final temperature to obtain the change in temperature, or delta T. The change in temperature may then be divided by the length of the TAP. Accordingly, the temperature ROC may be determined at the conclusion of the TAP.

[0055] At step **310**, method **300** may include determining one or more parameters for a feedback controlled cooking phase of the heating operation. The one or more parameters may be determined according to the determined temperature ROC at the temperature sensor. Moreover, the one or more parameters may include at least one controller gain. As mentioned above, the cooking phase of the heating operation may be performed as a feedback controlled phase, such as through a PID controller. Accordingly, the controller gains for the feedback controlled cooking phase may vary according to a particular cookware item used for the heating operation (e.g., such as large or small, material type, surface area in contact with the cooktop, etc.).

[0056] In determining the controller gains, method **300** may include determining (e.g., retrieving, calculating, etc.) a set of coefficients for the at least one controller gain value. In some instances, an individual set of coefficients may be determined for each controller gain value. As mentioned above, the feedback controlled cooking phase may be controlled by a PID controller. As such each of a proportional controller gain, an integral controller gain, and a derivative controller gain may be determined. However, it should be understood that any combination of proportional, integral, and derivative terms may be incorporated. Accordingly, a set of proportional coefficients may be determined, a set of integral coefficients may be determined, and a set of derivative coefficients may be determined.

[0057] Each of the set of proportional coefficients, the set of integral coefficients, and the set of derivative coefficients may include a first coefficient and a second coefficient. As described above, the first and second coefficients for each controller gain value may be incorporated into an equation to determine the appropriate controller gain value together with the determined temperature ROC. Referring again to FIG. **7**, one or more lookup tables may be incorporated (e.g., into the cooking appliance) in which a plurality of sets of coefficients may be stored. Thus, each respective set of coefficients may be retrieved from the lookup table or tables. Additionally or alternatively, each coefficient may be determined from known coefficients. For instance, in the case where a determined temperature ROC does not have a corresponding set of coefficients, an appropriate set of coefficients may be determined by calculating (e.g., interpolating) between two known sets of coefficients.

[0058] In some instances, as mentioned above, the determined temperature ROC may be compared against a predetermined threshold ROC. Referring again briefly to FIG. **5**, the predetermined threshold ROC may be provided for a plurality of temperature setpoints. For instance, the predetermined threshold ROC may be plotted as a line (e.g., as seen in FIG. **5**). In comparing the determined temperature ROC against the predetermined threshold ROC, method **300** may determine a material property of the cookware item. For instance, as shown for each particular temperature setpoint, the determined temperature ROC may indicate whether the cookware item is or includes cast iron or stainless steel. According to one example, method **300** determines that the cookware item includes a first material (e.g., cast iron) when the determined temperature ROC is greater than the predetermined threshold ROC, and determines that the cookware item includes a second material (e.g., stainless steel) when the determined temperature ROC is less than the predetermined threshold ROC (e.g., at a particular temperature setpoint). It should be noted that additional or alternative properties or materials may be determined according to the temperature ROC.

[0059] Additionally or alternatively, referring again to FIG. **7**, method **300** may determine the temperature setpoint for performing (or initiating) the heating operation. Accordingly, in determining (e.g., retrieving) the proper sets of coefficients (e.g., for each of the proportional, integral, and derivative controller gains), method **300** may consider the temperature setpoint. For instance, each of the determined cookware item material composition and the temperature setpoint may be considered when determining the corresponding sets of coefficients. For instance, for a particular temperature setpoint, a first set of coefficients for each of the proportional, integral, and derivative terms may be provided or stored for a cookware item including the first material, and a second set of coefficients for each of the proportional, integral, and derivative terms may be provided or stored for a cookware item including the second material.

[0060] Further, as mentioned above, each of the coefficients may be determined according to one or more calculations (e.g., interpolations) of known coefficients. For instance, when a temperature setpoint differs from a known or stored temperature setpoint, the associated coefficient values may be interpolated from known coefficients pertaining to surrounding temperature setpoints. For example, when a temperature setpoint is 275° F. and coefficients are known for temperature setpoints of 250° F. and 300° F., those known coefficients may be averaged together to determine the appropriate coefficients for the 275° F. temperature setpoint.

[0061] At step **312**, method **300** may include directing the at least one heating element according to the one or more determined parameters for a duration of the feedback controlled cooking phase. Upon determining the appropriate controller gains for the cooking phase using the temperature ROC and the corresponding sets of coefficients, method **300** may initiate the feedback controlled cooking phase. At this stage, the at least one heating element may be controlled according to the closed-loop control system as dictated by the controller gains.

[0062] This written description uses examples to disclose the invention, including the best mode, and also to enable any person skilled in the art to practice the invention, including making and using any devices or systems and performing any incorporated methods. The patentable scope of the invention is defined by the claims, and may include other examples that occur to those skilled in the art. Such other examples are intended to be within the scope of the claims if they include structural elements that do not differ from the literal language of the claims, or if they include equivalent structural elements with insubstantial differences from the literal languages of the claims.

What is claimed is:

1. A cooking appliance comprising:

at least one heating element to selectively supply heat to a cookware item;

a temperature sensor configured to selectively monitor a temperature of the cookware item; and

a controller operably connected with the at least one heating element and the temperature sensor, the controller configured to perform a heating operation, the heating operation comprising:

determining a temperature setpoint;

determining a power level for the at least one heating element based on the determined temperature setpoint;

directing the at least one heating element over a thermal analysis phase according to the determined power level;

determining a temperature rate of change at the temperature sensor at a conclusion of the thermal analysis phase;

determining one or more parameters for a feedback controlled cooking phase according to the determined temperature rate of change at the temperature sensor, the one or more parameters comprising at least one controller gain value; and

directing the at least one heating element according to the one or more determined parameters for a duration of the feedback controlled cooking phase.

2. The cooking appliance of claim **1**, wherein determining the one or more parameters for the feedback controlled cooking phase comprises:

determining a set of coefficients for the at least one controller gain value, the set of coefficients comprising a first coefficient and a second coefficient.

3. The cooking appliance of claim **2**, wherein determining the set of coefficients for the at least one controller gain value comprises:

determining a set of proportional coefficients for a proportional gain value;

determining a set of integral coefficients for an integral gain value; and

determining a set of derivative coefficients for a derivative gain value.

4. The cooking appliance of claim **3**, wherein each of the proportional gain value and the integral gain value is directly proportional to the temperature rate of change at the temperature sensor, and the derivative gain value is inversely proportional to the temperature rate of change at the temperature sensor.

5. The cooking appliance of claim **3**, wherein determining the one or more parameters for the feedback controlled cooking phase of the heating operation comprises:

determining the proportional gain value using an equation incorporating the set of proportional coefficients and the determined temperature rate of change;

determining the integral gain value using an equation incorporating the set of integral coefficients and the determined temperature rate of change; and

determining the derivative gain value using an equation incorporating the set of derivative coefficients and the determined temperature rate of change.

6. The cooking appliance of claim **3**, wherein each of the set of proportional coefficients, the set of integral coefficients, and the set of derivative coefficients is retrieved from a lookup table.

7. The cooking appliance of claim **3**, wherein the heating operation further comprises:

comparing the temperature rate of change at the temperature sensor against a predetermined threshold rate of change at the temperature setpoint;

determining a material composition of the cookware item based on the comparison of the temperature rate of change at the temperature sensor against the predetermined threshold rate of change, wherein the cookware item comprises one of a first material corresponding to the temperature rate of change being greater than the predetermined threshold rate of change or a second material corresponding to the temperature rate of change being less than the predetermined threshold rate of change.

8. The cooking appliance of claim **7**, wherein:

determining the set of proportional coefficients for the proportional gain value comprises retrieving a first set of proportional coefficients when the cookware item comprises the first material and retrieving a second set of proportional coefficients when the cookware item comprises the second material;

determining a set of integral coefficients for the integral gain value comprises retrieving a first set of integral coefficients when the cookware item comprises the first material and retrieving a second set of integral coefficients when the cookware item comprises the second material; and

determining a set of derivative coefficients for the proportional gain value comprises retrieving a first set of derivative coefficients when the cookware item comprises the first material and retrieving a second set of derivative coefficients when the cookware item comprises the second material.

9. The cooking appliance of claim **8**, wherein each of the set of proportional coefficients, the set of integral coefficients, and the set of derivative coefficients varies according to the temperature setpoint.

10. A method of operating a cooking appliance, the cooking appliance comprising at least one heating element and a temperature sensor, the method comprising:

determining a temperature setpoint for a heating operation of a cookware item;

determining a power level for the at least one heating element based on the determined temperature setpoint;

directing the at least one heating element over a thermal analysis phase according to the determined power level;

determining a temperature rate of change at the temperature sensor at a conclusion of the thermal analysis phase;

determining one or more parameters for a feedback controlled cooking phase according to the determined temperature rate of change at the temperature sensor, the one or more parameters comprising at least one controller gain value; and

directing the at least one heating element according to the one or more determined parameters for a duration of the feedback controlled cooking phase.

11. The method of claim **10**, wherein determining the one or more parameters for the feedback controlled cooking phase comprises:

determining a set of coefficients for the at least one controller gain value, the set of coefficients comprising a first coefficient and a second coefficient.

12. The method of claim **11**, wherein determining the set of coefficients for the at least one controller gain value comprises:

determining a set of proportional coefficients for a proportional gain value;

determining a set of integral coefficients for an integral gain value; and

determining a set of derivative coefficients for a derivative gain value.

13. The method of claim **12**, wherein each of the proportional gain value and the integral gain value is directly proportional to the temperature rate of change at the temperature sensor, and the derivative gain value is inversely proportional to the temperature rate of change at the temperature sensor.

14. The method of claim **12**, wherein determining the one or more parameters for the feedback controlled cooking phase of the heating operation comprises:

determining the proportional gain value using an equation incorporating the set of proportional coefficients and the determined temperature rate of change;

determining the integral gain value using an equation incorporating the set of integral coefficients and the determined temperature rate of change; and determining the derivative gain value using an equation incorporating the set of derivative coefficients and the determined temperature rate of change.

15. The method of claim **12**, wherein each of the set of proportional coefficients, the set of integral coefficients, and the set of derivative coefficients is retrieved from a lookup table.

16. The method of claim **12**, wherein the heating operation further comprises:

comparing the temperature rate of change at the temperature sensor against a predetermined threshold rate of change at the temperature setpoint;

determining a material composition of the cookware item based on the comparison of the temperature rate of change at the temperature sensor against the predetermined threshold rate of change, wherein the cookware item comprises one of a first material corresponding to the temperature rate of change being greater than the predetermined threshold rate of change or a second material corresponding to the temperature rate of change being less than the predetermined threshold rate of change.

17. The method of claim **16**, wherein:

determining the set of proportional coefficients for the proportional gain value comprises retrieving a first set of proportional coefficients when the cookware item comprises the first material and retrieving a second set of proportional coefficients when the cookware item comprises the second material;

determining a set of integral coefficients for the integral gain value comprises retrieving a first set of integral coefficients when the cookware item comprises the first material and retrieving a second set of integral coefficients when the cookware item comprises the second material; and

determining a set of derivative coefficients for the proportional gain value comprises retrieving a first set of derivative coefficients when the cookware item comprises the first material and retrieving a second set of derivative coefficients when the cookware item comprises the second material.

18. The method of claim **17**, wherein each of the set of proportional coefficients, the set of integral coefficients, and the set of derivative coefficients varies according to the temperature setpoint.

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