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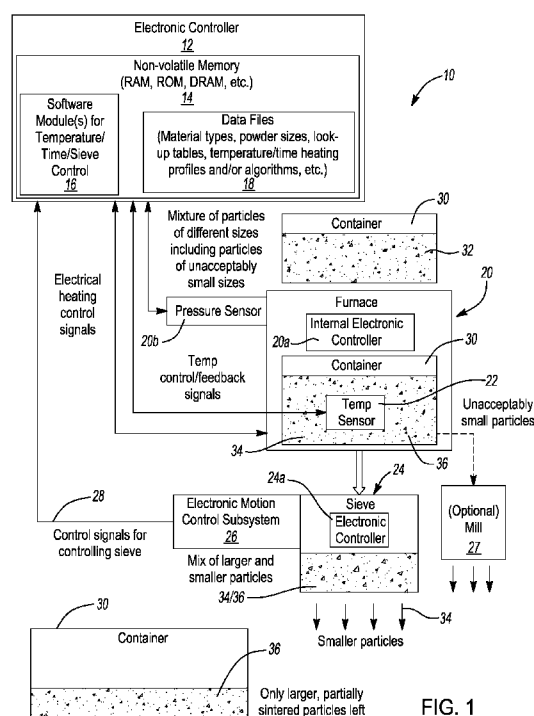
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(54) Title: SYSTEMS AND METHODS FOR PARTIAL SINTERING OF POWDER TO CREATE LARGER POWDER PARTICLES FOR ADDITIVE MANUFACTURING PROCESSES



(57) Abstract: A system for creating a second quantity of sinterable powder particles which have sizes falling within a second size range, from a first quantity of sinterable powder particles having sizes falling within a first size range, and where the sizes of the powder particles in the second size range are all larger than those in the first size range. In one embodiment the system has a heating component responsive to a predetermined temperature/time heating profile, which heats the first quantity of powder particles using the temperature/time heating profile, to cause partial sintering of the powder particles, which creates a new plurality of powder particles which have an increased dimension. A movement component is incorporated to at least one of separate the new powder particles from remaining ones of the powder particles of the first quantity of powder particles, or to further process the new plurality of powder particles, such that the new plurality of powder particles represents the second quantity of sinterable powder particles.

FIG. 1

SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN,
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SYSTEMS AND METHODS FOR PARTIAL SINTERING OF POWDER TO CREATE LARGER POWDER PARTICLES FOR ADDITIVE MANUFACTURING PROCESSES

CROSS-REFERENCE TO RELATED APPLICATIONS

5 **[0001]** This application is a PCT International Application and claims priority to United States Patent Application No. 17/991,642, filed on November 21, 2022. The entire disclosure of the above application is incorporated herein by reference.

FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

10 **[0002]** This invention was made with Government support under Contract No. DE-AC52-07NA27344 awarded by the United States Department of Energy. The Government has certain rights in the invention.

FIELD

15 **[0003]** The present disclosure relates to systems and methods for processing granular material, such as powders, that are often used in additive manufacturing applications as feedstock material, and more particularly to systems and methods for reprocessing granular particles which are too small for use in an additive manufacturing application into larger size particles suitable for use in additive manufacturing
20 applications.

BACKGROUND

[0004] The statements in this section merely provide background information related to the present disclosure and may not constitute prior art.

[0005] Powder processing is used for creating powder particles that are of
25 suitable sizes to be used in additive manufacturing applications as a feedstock material. The powder particles are of materials that are able to be melted or sintered, typically using a laser, to produce parts using an additive manufacturing system. Sintering is the process where powder particles are heated to a high temperature below their melting point, and solid diffusion occurs. During the sintering process, particles located next to
30 each other will fuse, or sinter, together where they are in contact. Typically sintering is used to make near full density solid parts by allowing strong bonds and networks to form between neighboring particles. This process typically takes many hours or days to occur,

depending on the material properties and temperature used in the manufacturing process.

[0006] During typical powder making processes, a wide distribution of powder particle sizes is often produced. Although efforts are made to optimize the powder particles for a desired, final size distribution, there are always some powder particles produced that are too small and fall below the desired final powder size or size range. Depending on the powder material (i.e., metal vs. ceramic powders), the undersized powder particles are either remelted or pressed into a solid part, and then recycled back into the powder making process. This process requires extra steps, that is, pressing or remelting in addition to the powder making process, and can require significant extra time and energy, resulting in increased costs overall.

[0007] Accordingly, a need exists for particle manufacturing systems and methods which can increase the size of meltable or sinterable powder particles which are below a minimum acceptable size range, and without the added time and expense of remelting the smaller-than-acceptable powder particles. Such systems and method can be expected to save time, energy and costs in the re-processing of smaller-than-acceptable powder particles.

SUMMARY

[0008] This section provides a general summary of the disclosure, and is not a comprehensive disclosure of its full scope or all of its features.

[0009] In one aspect the present disclosure relates to a method for creating a second quantity of sinterable powder particles which have sizes falling within a second size distribution range, from a first quantity of sinterable powder particles having sizes falling within a first size distribution range, and where the sizes of the powder particles in the second size distribution range are all larger than the sizes of the particles in the first size distribution range. The method may comprise heating the first quantity of sinterable powder particles using a predetermined temperature/time heating profile sufficient to cause partial sintering of ones of the powder particles within the first quantity of sinterable powder particles, to create a new plurality of powder particles which have an increased dimension. The method may also include processing the new powder particles such that the new plurality of powder particles represents the second quantity of sinterable powder particles.

[0010] In another aspect of the present disclosure the system may further comprise an electronic controller configured to generate control signals to apply the temperature/time heating profile to the heating component.

5 [0011] In another aspect of the present disclosure the system may comprise a memory in communication with the electronic controller for storing the temperature/time heating profile.

[0012] In another aspect of the present disclosure the memory is configured to store a plurality of different temperature/time profiles for different types of powder particles.

10 [0013] In another aspect of the present disclosure the memory further includes at least one data file including at least one of: characteristics of the powder particles of the first quantity of powder particles; a desired size distribution range for at least one specific type of powder particles; sintering temperatures and duration needed for sintering different types of powder particles; or atmospheric conditions, including at least
15 one of gas or vacuum, during sintering.

[0014] In another aspect the of present disclosure the heating component comprises a furnace.

[0015] In another aspect of the present the movement component is configured to at least one of separate or further process the first quantity of sinterable powder
20 particles to provide the new plurality of powder particles comprises a sieve to separate out, through vibration or movement thereof, the new plurality of powder particles from remaining ones of the first quantity of sinterable powder particles.

[0016] In another aspect of the present disclosure the component that at least one of separates or further processes the new plurality of powder particles comprises a
25 mill which carries out a milling operation to process the new plurality of powder particles to form modified powder particles which all have the second size distribution.

[0017] In another aspect of the present disclosure the modified powder particles comprise dimensions which are larger than the second size distribution, and the milling operation breaks down the modified powder particles to reduce dimensions of the
30 modified powder particles to produce the second quantity of powder particles which have the second size distribution.

[0018] In another aspect of the present disclosure the temperature of the heating component is monitored by the electronic controller, and adjusted when needed, while the partial sintering of the first quantity of powder particles is occurring.

5 [0019] In another aspect of the present disclosure the system further comprises an electronic controller for assisting in controlling the sieve.

[0020] In another aspect the present disclosure relates to a system for creating a second quantity of sinterable powder particles which have sizes falling within a second size distribution range, from a first quantity of sinterable powder particles having sizes falling within a first size distribution range, and where the sizes of the powder particles in
10 the second size distribution range are all larger than the sizes of the particles in the first size distribution range. The system may comprise a heating component configured to apply a predetermined, temperature/time heating profile to the first quantity of sinterable powder particles to controllably heat the first quantity of sinterable powder particles using the temperature/time heating profile, to cause partial sintering of ones of the powder
15 particles within the first quantity of sinterable powder particles to create a new plurality of powder particles which have an increased dimension. The system may also include a sieve controlled to separate the new powder particles from remaining ones of the powder particles of the first quantity of sinterable powder particles, such that the new plurality of powder particles represents the second quantity of sinterable powder particles.

20 [0021] In another aspect of the present disclosure the system further comprises an electronic controller for generating electrical control signals for applying the predetermined, temperature/time heating profile to the heating component.

[0022] In another aspect of the present disclosure the system comprises a memory in communication with the controller for storing the temperature/time heating
25 profile.

[0023] In another aspect of the present disclosure the memory is further configured to store data for sintering different compositions of powder particles.

[0024] In another aspect of the present disclosure the system the electronic controller assists in controlling operation of the sieve.

30 [0025] In still another aspect the present disclosure relates to a system for creating a second quantity of sinterable powder particles which have sizes falling within a second size distribution range, from a first quantity of sinterable powder particles having sizes falling within a first size distribution range, and where the sizes of the powder

particles in the second size distribution range are all larger than the sizes of the particles in the first size distribution range. The system may comprise a heating component configured to apply a predetermined, temperature/time heating profile to the first quantity of sinterable powder particles to controllably heat the first quantity of sinterable powder particles using the temperature/time heating profile, to cause partial sintering of ones of the powder particles within the first quantity of sinterable powder particles to create a new plurality of powder particles which each have an increased dimension larger than the second size distribution range. The system may also include a mill controlled to further process the new plurality of powder particles to break down the new plurality of powder particles such that each one of the new of plurality of powder particles is reduced in dimensions to fall within the second distribution range.

[0026] In another aspect of the present disclosure the system further comprises an electronic controller for generating electrical control signals for applying the predetermined, temperature/time heating profile to the heating component.

[0027] In another aspect of the present disclosure the system further comprises a memory in communication with the controller for storing the temperature/time heating profile.

[0028] In another aspect the present disclosure relates to a method for creating a second quantity of sinterable powder particles which have sizes falling within a second size distribution range, from a first quantity of sinterable powder particles having sizes falling within a first size distribution range, and where the sizes of the powder particles in the second size distribution range are all larger than the sizes of the particles in the first size distribution range. The method may comprise heating the first quantity of sinterable powder particles using a predetermined temperature/time heating profile sufficient to cause partial sintering of ones of the powder particles within the first quantity of sinterable powder particles, to create a new plurality of powder particles which have an increased dimension. The method may also include further processing the new powder particles such that the new plurality of powder particles represents the second quantity of sinterable powder particles.

[0029] Further areas of applicability will become apparent from the description provided herein. It should be understood that the description and specific examples are intended for purposes of illustration only and are not intended to limit the scope of the present disclosure.

BRIEF DESCRIPTION OF THE DRAWINGS

[0030] The drawings described herein are for illustrative purposes only of selected embodiments and not all possible implementations and are not intended to limit the scope of the present disclosure.

5 **[0031]** Corresponding reference numerals indicate corresponding parts throughout the several views of the drawings.

[0032] Figure 1 is a high level schematic view of one example of a system in accordance with the present disclosure for creating larger particles from a quantity of smaller-than-acceptably dimensioned powder particles;

10 **[0033]** Figure 2 is a high level flowchart setting forth one example of operations that may be performed by a method of the present disclosure in partially sintering a quantity of smaller-than-acceptably dimensioned powder particles to create larger dimensioned powder particles which have dimensions making them suitable for use in an AM process; and

15 **[0034]** Figure 3 is a flowchart setting forth another example of operations that may be performed by a method of the present disclosure, which involves partially sintering a quantity of smaller-than-acceptably dimensioned powder particles to produce partially sintered powder particles which are larger than desired, and then using a milling operation to reduce the size of the particles down to an acceptable dimension, and finally
20 performing a sieving action to remove remaining ones of the powder particles that are smaller than acceptable in dimension.

DETAILED DESCRIPTION

[0035] Example embodiments will now be described more fully with reference
25 to the accompanying drawings.

[0036] The present disclosure relates to systems and methods for partially sintering smaller-than-acceptable sized powder particles to increase the size of the powder particles without producing fully dense, or near fully dense, powder particles. Instead, the smaller-than-acceptable sized powder particles are collected into a quantity
30 and the quantity is heated to a predetermined high temperature. The quantity of powder particles are then held at the predetermined temperature for a shorter amount of time than required to produce a fully sintered part. During this time, neighboring powder particles sinter together. However, because the time is too short to allow for a full-

strength network to develop, the quantity of powder remains a quantity of powder particles, but with the powder particles having an increased size when the partial sintering has been completed. Thus, the powder particle size is increased without the formation of a strong part.

5 **[0037]** Referring to Figure 1, a system 10 in accordance with one embodiment of the present disclosure is shown. The system 10 in this example may include an electronic controller 12 having a memory 14, which may be a non-volatile memory. The non-volatile memory 14 may include one or more software modules 16 for carrying out
10 as well as for controlling sieve movement controls signals. One or more data files 18 may also be stored in the memory 14. The data files 18 may relate to temperature/time curves to be used for various powdered materials, characteristics of different powder materials, sintering temperatures needed for different types of materials, particle size distribution ranges which are desired for different types of powder particles, etc.

15 **[0038]** The system 10 may also include a furnace 20, or the furnace may be a separate component which the system 10 is used with. If the furnace 20 forms a portion of the system 10, the furnace may include an internal electronic controller 20a and/or a temperature sensor 22. The temperature sensor 22 may be in communication with the internal electronic controller 20a, and/or it may be in communication with the electronic
20 controller 12. Similarly, the internal electronic controller 20a of the furnace 20 may be in communication with the electronic controller 12. In any one of these configurations, the temperature sensor 22 may provide real time temperature data to the electronic controller 20a and/or the electronic controller 12. In this regard, the furnace 20 may be primarily responsible for controlling and monitoring the heating of powder particles using its
25 internal controller 20a, or the electronic controller 12 may be performing these operations. Still further, the two electronic controllers 20a and 12 may share one or more of the heating and temperature monitoring responsibilities. Preferably, the temperature sensor 22 is located within the powder particles being heated to optimize measurement accuracy of the temperature being experienced by the powder particles. The furnace 20 is
30 preferably operated to perform heating in a vacuum environment, or optionally it may be operated so that the heating is performed in an environment using argon, helium, or another inert gas to help prevent oxidation of the powder particles.

[0039] The furnace 20 may also include a pressure sensor 20b which may be monitored by the internal electronic controller 20a or optionally by the electronic controller 12. The pressure sensor 20a provides a pressure output signal indicating an atmospheric condition within the furnace 20, which is helpful and desirable to monitor during heating, and particularly if a vacuum environment needs to be maintained within the furnace during its operation

[0040] A sieve 24, which forms a movement component, may also be included as part of the system 10, or the sieve may be a component which is interfaced to the system. The sieve 24 may include its own internal electronic controller 24a as well as an electronically controlled motion subsystem 26. The motion subsystem 26 may cause vibration, agitation, and/or X/Y axis movement of the sieve to help facilitate the separation and removal of different sized powder particles held within the sieve. If the electronic motion control subsystem 26 is included, and the subsystem 26 includes a suitable communications interface, then a communications control line 28 may be coupled to an output port of the electronic controller 12 to enable the electronic controller 12 to control the electronic motion control subsystem 26 as needed to carry out the separation of different sized particles held within the sieve 24. Optionally, the electronic controller 12 may be configured to communicate with the internal electronic controller 24a of the sieve as well, to partially or fully help control operation of the sieve 24.

[0041] In some embodiments the system 10 may also include a mill 27. The mill 27 may be used for breaking down larger-than-desired powder particles, as will be explained further in the following paragraphs. The mill 27 is used to act on powder particles after the powder particles are partially sintered using the furnace 20, or alternatively after the powder particles are separated using the sieve 24. In some implementations two or more alternating milling and sieving operations may also be performed to provide a potentially finer granularity or even closer dimensional tolerance range for the finished powder particles or to increase yield.

[0042] With further reference to Figure 1 and a flowchart 100 of Figure 2, one sequence of operations in accordance with the present disclosure for creating larger powder particles with a desired particle size distribution from a quantity of smaller-than-acceptably sized powder particles will be described. Initially a container 30 may be used to hold a quantity of powder particles 32 which have dimensions of varying sizes, but which are too small for use in an additive manufacturing ("AM") process. In other words, the

quantity of powder particles 32 is formed by powder particles which do not meet a minimum dimension requirement for use in an AM process. The quantity of powder particles 32 may be made up of metal powder particles, ceramic powder particles, a mixture thereof, or any other composition of powder particles which is sinterable in an AM process.

[0043] At operation 102 in Figure 2, the powder particles 32 are loaded into the container 30. At operation 104 the container 30 may be heated, such as by placing the container 30 in the furnace 20, for a predetermined time period using a predetermined heating profile that raises the temperature of the powder particles 32 to a predetermined temperature which is below the melting point of the powder particles, but which is still sufficient to cause partial sintering of the powder particles. The powder particles 32 are heated for a predetermined time period. In one implementation the software modules 16 include an algorithm for implementing a ramp-up/hold/ramp-down heating profile. This heating profile may vary significantly depending on the specific composition of the powder particles, but in one example a heating profile including a temperature ramp-up to about 700° C within about 30 minutes – 1 hour, a hold at about 700 C for between about 4-24 hours, and a cooling period of at least about 2-3 hours, and in some instances longer (e.g., 12 hours) may be used. The average starting dimensions of the powder particles, as well as their composition, may both influence the selection of an optimum heating profile. Creating larger sized, partially sintered particles may be expected to require a longer hold time. Optionally, an active cooling system may be employed to enable a more controlled and/or extended temperature ramp-down (i.e., cooling period) to reduce and/or eliminate tensions on the bonds of newly partially sintered powder particles. Specific parameters will be material specific. The temperature and heating time may be controlled by the electronic controller 12 by using one or more items of the stored information in the data files 18, for example the specific composition of the powder particles that are being processed and/or the desired size distribution of the finished powder particles. In one embodiment the heating may be monitored in real time by the electronic controller 12, by which the electronic controller monitors the temperature of the powder particles 32 as the heating process is carried out, and makes temperature adjustments in real time, as needed, to maintain a desired temperature/time heating profile. Alternatively, the heating may be carried out by the electronic controller 12 using an open loop process where a fixed, temperature/time heating profile, suitable for the

particular composition of powder particles being acted on, and a specific desired particle size distribution range, has been determined in advance, and is simply applied by the electronic controller 12 without the use of any real time temperature feedback control. One or more temperature/time/particle composition look-up tables may be used for the open loop approach. Thus, each of the ramp-up, hold and ramp-down portions of the heating profile may be implemented in either a closed loop or open loop fashion.

[0044] While the heating described above is occurring, neighboring powder particles within the quantity of powder particles will partially sinter together. However, because the heating time is too short to allow for a full-strength network to develop, the powder particles remain as powder particles when the partial sintering has been completed. Thus, the particle size of many of the powder particles will increase but without forming a single, fully formed part from the full quantity of the powder particles.

[0045] At operation 106 in Figure 2, the container 30 may then be removed from the furnace 20 and the container will be allowed to cool further. The cooling period may be sufficient to allow the quantity of powder particles 34/36 to reach room temperature, or nearly room temperature, over a predetermined temperature ramp-down cooling period.

[0046] It will be understood that the container 30 will now contain a quantity of powder particles with different particle size distributions than the quantity of powder particles 32. More specifically, a subquantity of the powder particles will still be unacceptably small particles, and this is indicated in Figure 1 using reference number 34, while another subquantity of the powder particles will be newly formed, larger sized powder particles 36. The larger sized powder particles 36 are partially sintered powder particles made up of two or more ones of the unacceptably small powder particles 34 and will be within a dimensional range making them suitable for use in an AM process.

[0047] At operation 108 in Figure 2, once the quantity of powder particles 34/36 has cooled sufficiently it may be sieved. This may be accomplished by placing the quantity of powder particles 34/36 in the sieve 24 and operating the sieve for a predetermined time period sufficient to cause the still smaller-than-acceptable powder particles 34 within the quantity of powder particles 34/36 to fall out of the sieve 24. The powder particles remaining in the sieve 24 will be only the partially sintered powder particles 36 which have dimensions within a desired size range making them acceptable for use in an AM process. The desired size range may vary significantly depending on a

number of factors, for example material composition, powder flowability, or powder shape, just to name a few such factors. In some AM applications powder particles having a diameter of about 15 microns to about 70 microns is particularly preferred. In some AM applications powder particles having a diameter of between about 15 microns to about 45 microns is more preferred. The system 10 of the present disclosure is able to create particles within these dimensional ranges, as well as particles with dimensions outside these ranges, efficiently and economically.

[0048] Lastly, in Figure 2, operation 110 is an optional operation where further processing of the quantity of powder particles 36 may be undertaken. This optional processing may involve one or more operations involving spheridizing the particles (i.e., making the particles more spherical, typically by melting and allowing the particles to solidify during freefall), further sorting the quantity of powder particles 36 into one or more different particle size distributions, etc.

[0049] Figure 3 shows a flowchart 200 illustrating another process in accordance with the present disclosure for creating powder particles of a desired size distribution from a starting quantity of smaller-than-acceptable dimensioned powder particles. Operation 202 is similar to operation 102 wherein a quantity of powder particles, such as the quantity of smaller-than-acceptable dimensioned powder particles 32 shown in Figure 1, is initially loaded into the container 30. At operation 204 the needed data on powder material property(ies), desired particle size distribution, needed temperature/heating profile(s) etc. may be obtained by the electronic controller 12 from the data files 18. However, the temperature/heating profile(s) used will be such as to cause significant particle sintering to occur such that most, or all, of the powder particles comprise a new quantity of powder particles which are now unacceptably large for use in an AM application. The heating may be carried out using the furnace 20 or any other suitable implement.

[0050] At operation 208, once the heating operation has been carried out using the predetermined heating/temperature profile and the heating time has expired, the new quantity of powder particles are allowed to cool for a predetermined time period (e.g., to reach room temperature or nearly room temperature). The cooled powder particles will now be mostly, or all, of a size which is larger than desired, although a small quantity of smaller-than-acceptable dimensioned powder particles will typically still exist. At operation 210, the new, larger-than-acceptable quantity of powder particles may be

placed in a mill, for example mill 24a shown in Figure 1, and broken down using a milling action to such that a majority of all the powder particles fall within a desired particle size distribution and produce a finished quantity of powder particles. At operation 212 a sieving operation may then be performed to remove the small quantity of powder particles that remain, and which are still smaller-than-acceptable, which leaves only the particles with a desired particle distribution range. Alternatively, the milling action 210 may be performed after the sieving operation 212. Still further, the sieving action 210 could be performed before, and then again after, the milling operation 212. Optionally the mill-sieve-mill-sieve operations could be performed multiple times if needed. Further processing may optionally be performed at operation 214 to spheridize or package the finished quantity of powder particles.

[0051] In either of the process described above for the flowcharts of Figures 2 and 3, the resulting larger dimensioned powder particles of a porous nature, since they are composed of several smaller particles sintered together with significant voids between them. As such, different temperature/time profiles can be used to create powder particles having differing, unique porous properties. It is expected that this advancement may be utilized to produce parts having engineered porosities. For example, some possible applications may include catalyst development, biomedical implants (providing ample surface area to grab on to), supported, lightweight structures or ceramics. Some or all of these possible applications may require further processing beyond what is described in the present disclosure to get from particle to finished shape, but such applications are expected to be of interest, in view of the teachings presented herein.

[0052] The foregoing description of the embodiments has been provided for purposes of illustration and description. It is not intended to be exhaustive or to limit the disclosure. Individual elements or features of a particular embodiment are generally not limited to that particular embodiment, but, where applicable, are interchangeable and can be used in a selected embodiment, even if not specifically shown or described. The same may also be varied in many ways. Such variations are not to be regarded as a departure from the disclosure, and all such modifications are intended to be included within the scope of the disclosure.

[0053] Example embodiments are provided so that this disclosure will be thorough, and will fully convey the scope to those who are skilled in the art. Numerous specific details are set forth such as examples of specific components, devices, and

methods, to provide a thorough understanding of embodiments of the present disclosure. It will be apparent to those skilled in the art that specific details need not be employed, that example embodiments may be embodied in many different forms and that neither should be construed to limit the scope of the disclosure. In some example embodiments, well-known processes, well-known device structures, and well-known technologies are not described in detail.

[0054] The terminology used herein is for the purpose of describing particular example embodiments only and is not intended to be limiting. As used herein, the singular forms “a,” “an,” and “the” may be intended to include the plural forms as well, unless the context clearly indicates otherwise. The terms “comprises,” “comprising,” “including,” and “having,” are inclusive and therefore specify the presence of stated features, integers, steps, operations, elements, and/or components, but do not preclude the presence or addition of one or more other features, integers, steps, operations, elements, components, and/or groups thereof. The method steps, processes, and operations described herein are not to be construed as necessarily requiring their performance in the particular order discussed or illustrated, unless specifically identified as an order of performance. It is also to be understood that additional or alternative steps may be employed.

[0055] When an element or layer is referred to as being “on,” “engaged to,” “connected to,” or “coupled to” another element or layer, it may be directly on, engaged, connected or coupled to the other element or layer, or intervening elements or layers may be present. In contrast, when an element is referred to as being “directly on,” “directly engaged to,” “directly connected to,” or “directly coupled to” another element or layer, there may be no intervening elements or layers present. Other words used to describe the relationship between elements should be interpreted in a like fashion (e.g., “between” versus “directly between,” “adjacent” versus “directly adjacent,” etc.). As used herein, the term “and/or” includes any and all combinations of one or more of the associated listed items.

[0056] Although the terms first, second, third, etc. may be used herein to describe various elements, components, regions, layers and/or sections, these elements, components, regions, layers and/or sections should not be limited by these terms. These terms may be only used to distinguish one element, component, region, layer or section from another region, layer or section. Terms such as “first,” “second,” and other

numerical terms when used herein do not imply a sequence or order unless clearly indicated by the context. Thus, a first element, component, region, layer or section discussed below could be termed a second element, component, region, layer or section without departing from the teachings of the example embodiments.

5 **[0057]** Spatially relative terms, such as “inner,” “outer,” “beneath,” “below,” “lower,” “above,” “upper,” and the like, may be used herein for ease of description to describe one element or feature's relationship to another element(s) or feature(s) as illustrated in the figures. Spatially relative terms may be intended to encompass different orientations of the device in use or operation in addition to the orientation depicted in the
10 figures. For example, if the device in the figures is turned over, elements described as “below” or “beneath” other elements or features would then be oriented “above” the other elements or features. Thus, the example term “below” can encompass both an orientation of above and below. The device may be otherwise oriented (rotated 90 degrees or at other orientations) and the spatially relative descriptors used herein
15 interpreted accordingly.

CLAIMS

What is claimed is:

1. A system for creating a second quantity of sinterable powder particles which
5 have sizes falling within a second size distribution range, from a first quantity of sinterable powder particles having sizes falling within a first size distribution range, and where the sizes of the powder particles in the second size distribution range are all larger than the sizes of the particles in the first size distribution range, the system comprising;
- a heating component responsive to a predetermined temperature/time heating
10 profile, and configured to heat the first quantity of sinterable powder particles using the temperature/time heating profile, to cause partial sintering of ones of the powder particles within the first quantity of sinterable powder particles to create a new plurality of powder particles which have an increased dimension; and
- a movement component to at least one of separate the new powder particles from
15 remaining ones of the powder particles of the first quantity of sinterable powder particles, or to further process the new plurality of powder particles, such that the new plurality of powder particles represents the second quantity of sinterable powder particles.
2. The system of claim 1, further comprising an electronic controller configured to
20 generating control signals to apply the temperature/time heating profile to the heating component.
3. The system of claim 2, further comprising a memory in communication with the
25 electronic controller for storing the temperature/time heating profile.
4. The system of claim 3, wherein the memory is configured to store a plurality of
different temperature/time profiles for different types of powder particles.
5. The system of claim 3, wherein the memory further includes at least one data
30 file including at least one of:
- characteristics of the powder particles of the first quantity of powder particles;
a desired size distribution range for at least one specific type of powder particles;

sintering temperatures and duration needed for sintering different types of powder particles; or

atmospheric conditions, including at least one of gas or vacuum, during sintering.

5 6. The system of claim 1, wherein the heating component comprises a furnace.

7. The system of claim 1, wherein the movement component to at least one of separate or further process the first quantity of sinterable powder particles to provide the new plurality of powder particles comprises a sieve to separate out, through vibration or
10 movement thereof, the new plurality of powder particles from remaining ones of the first quantity of sinterable powder particles.

8. The system of claim 1, wherein the component to at least one of separate or further process the new plurality of powder particles comprises a mill which carries out a
15 milling operation to process the new plurality of powder particles to form modified powder particles which all have the second size distribution.

9. The system of claim 8, wherein the modified powder particles comprise dimensions which are larger than the second size distribution, and the milling operation
20 breaks down the modified powder particles to reduce dimensions of the modified powder particles to produce the second quantity of powder particles which have the second size distribution.

10. The system of claim 2, wherein the temperature of the heating component is
25 monitored by the electronic controller, and adjusted when needed, while the partial sintering of the first quantity of powder particles is occurring.

11. The system of claim 7, further comprising an electronic controller for assisting
in controlling the sieve.

30 12. A system for creating a second quantity of sinterable powder particles which have sizes falling within a second size distribution range, from a first quantity of sinterable powder particles having sizes falling within a first size distribution range, and where the

sizes of the powder particles in the second size distribution range are all larger than the sizes of the particles in the first size distribution range, the system comprising;

a heating component configured to apply a predetermined, temperature/time heating profile to the first quantity of sinterable powder particles to controllably heat the first quantity of sinterable powder particles using the temperature/time heating profile, to cause partial sintering of ones of the powder particles within the first quantity of sinterable powder particles to create a new plurality of powder particles which have an increased dimension; and

a sieve controlled to separate the new powder particles from remaining ones of the powder particles of the first quantity of sinterable powder particles, such that the new plurality of powder particles represents the second quantity of sinterable powder particles.

13. The system of claim 12, further comprising an electronic controller for generating electrical control signals for applying the predetermined, temperature/time heating profile to the heating component.

14. The system of claim 13, further comprising a memory in communication with the controller for storing the temperature/time heating profile.

15. The system of claim 14, wherein the memory is further configured to store data for sintering different compositions of powder particles.

16. The system of claim 13, wherein the electronic controller assists in controlling operation of the sieve.

17. A system for creating a second quantity of sinterable powder particles which have sizes falling within a second size distribution range, from a first quantity of sinterable powder particles having sizes falling within a first size distribution range, and where the sizes of the powder particles in the second size distribution range are all larger than the sizes of the particles in the first size distribution range, the system comprising;

a heating component configured to apply a predetermined, temperature/time heating profile to the first quantity of sinterable powder particles to controllably heat the

first quantity of sinterable powder particles using the temperature/time heating profile, to cause partial sintering of ones of the powder particles within the first quantity of sinterable powder particles to create a new plurality of powder particles which each have an increased dimension larger than the second size distribution range; and

5 a mill controlled to further process the new plurality of powder particles to break down the new plurality of powder particles such that each one of the new of plurality of powder particles is reduced in dimensions to fall within the second distribution range.

18. The system of claim 17, further comprising an electronic controller for
10 generating electrical control signals for applying the predetermined, temperature/time heating profile to the heating component.

19. The system of claim 18, further comprising a memory in communication with
15 the controller for storing the temperature/time heating profile.

20. A method for creating a second quantity of sinterable powder particles which
have sizes falling within a second size distribution range, from a first quantity of sinterable
powder particles having sizes falling within a first size distribution range, and where the
sizes of the powder particles in the second size distribution range are all larger than the
20 sizes of the particles in the first size distribution range, the method comprising;

 heating the first quantity of sinterable powder particles using a predetermined
temperature/time heating profile sufficient to cause partial sintering of ones of the powder
particles within the first quantity of sinterable powder particles, to create a new plurality
of powder particles which have an increased dimension; and

25 further processing the new powder particles such that the new plurality of powder
particles represents the second quantity of sinterable powder particles.

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AMENDED CLAIMS

[received by the International Bureau on 10 May 2024 (10.05.2024)]

What is claimed is:

1. A system for creating a second quantity of sinterable powder particles which have sizes falling within a second size distribution range, from a first quantity of sinterable powder particles having sizes falling within a first size distribution range, and where the sizes of the powder particles in the second size distribution range are all larger than the sizes of the particles in the first size distribution range, the system comprising:

an electronic controller;

a heating component responsive to a predetermined temperature/time heating profile controlled by the electronic controller, the heating component being controlled to implement a temperature/time heating profile including a predetermined temperature ramp-up heating time period, followed by a predetermined temperature hold time period, followed by a predetermined cooling time period, and configured to heat the first quantity of sinterable powder particles using the temperature/time heating profile, to cause partial sintering of ones of the powder particles within the first quantity of sinterable powder particles to create a new plurality of powder particles which have an increased dimension; and

a movement component to at least one of separate the new powder particles from remaining ones of the powder particles of the first quantity of sinterable powder particles, or to further process the new plurality of powder particles, such that the new plurality of powder particles represents the second quantity of sinterable powder particles.

2. Cancelled.

3. The system of claim 1 further comprising a memory in communication with the electronic controller for storing the temperature/time heating profile.

4. The system of claim 3, wherein the memory is configured to store a plurality of different ones of the temperature/time profiles for different types of powder particles.

5. The system of claim 3, wherein the memory further includes at least one data file including at least one of:

characteristics of the powder particles of the first quantity of powder particles;
a desired size distribution range for at least one specific type of powder particles;
sintering temperatures and duration needed for sintering different types of powder particles; or

atmospheric conditions, including at least one of gas or vacuum, during sintering.

6. The system of claim 1, wherein the heating component comprises a furnace.

7. The system of claim 1, wherein the movement component to at least one of separate or further process the first quantity of sinterable powder particles to provide the new plurality of powder particles comprises a sieve to separate out, through vibration or movement thereof, the new plurality of powder particles from remaining ones of the first quantity of sinterable powder particles.

8. The system of claim 1, wherein the movement component to at least one of separate or further process the new plurality of powder particles comprises a mill which carries out a milling operation to process the new plurality of powder particles to form modified powder particles which all have the second size distribution.

9. The system of claim 8, wherein the milling operation breaks down the modified powder particles to reduce dimensions of the modified powder particles to produce the second quantity of powder particles which have the second size distribution.

10. The system of claim 1, wherein the temperature of the furnace is monitored and adjusted by the electronic controller while the partial sintering of the first quantity of powder particles is occurring.

11. The system of claim 7, wherein the electronic controller is configured to assist in controlling the sieve.

12. A system for creating a second quantity of sinterable powder particles which have sizes falling within a second size distribution range, from a first quantity of sinterable powder particles having sizes falling within a first size distribution range, and where the sizes of the powder particles in the second size distribution range are all larger than the sizes of the particles in the first size distribution range, the system comprising;

an electronic controller;

a heating component responsive to the electronic controller and configured to apply a predetermined, temperature/time heating profile including a predetermined temperature ramp-up time period, a predetermined temperature hold time period, and a predetermined cool down period to the first quantity of sinterable powder particles to controllably heat the first quantity of sinterable powder particles using the temperature/time heating profile, to cause partial sintering of ones of the powder particles within the first quantity of sinterable powder particles to create a new plurality of powder particles which have an increased dimension;

a sieve controlled to separate the new plurality of powder particles from remaining ones of the powder particles of the first quantity of sinterable powder particles, such that the new plurality of powder particles represents the second quantity of sinterable powder particles.

13. Cancelled.

14. The system of claim 12, further comprising a memory in communication with the electronic controller for storing the temperature/time heating profile.

15. The system of claim 14, wherein the memory is further configured to store data for sintering different compositions of powder particles.

16. The system of claim 13, wherein the electronic controller assists in controlling operation of the sieve.

17. A system for creating a second quantity of sinterable powder particles which have sizes falling within a second size distribution range, from a first quantity of sinterable powder particles having sizes falling within a first size distribution range, and where the sizes of the powder particles in the second size distribution range are all larger than the sizes of the particles in the first size distribution range, the system comprising:

an electronic controller;

a heating component responsive to the electronic controller, the heating component configured to apply a predetermined, temperature/time heating profile including a predetermined temperature ramp-up time period, a predetermined temperature hold time period, and a predetermined cool down period, to the first quantity of sinterable powder particles to controllably heat the first quantity of sinterable powder particles using the temperature/time heating profile, to cause partial sintering of ones of the powder particles within the first quantity of sinterable powder particles to create a new plurality of powder particles which each have an increased dimension larger than the second size distribution range: and

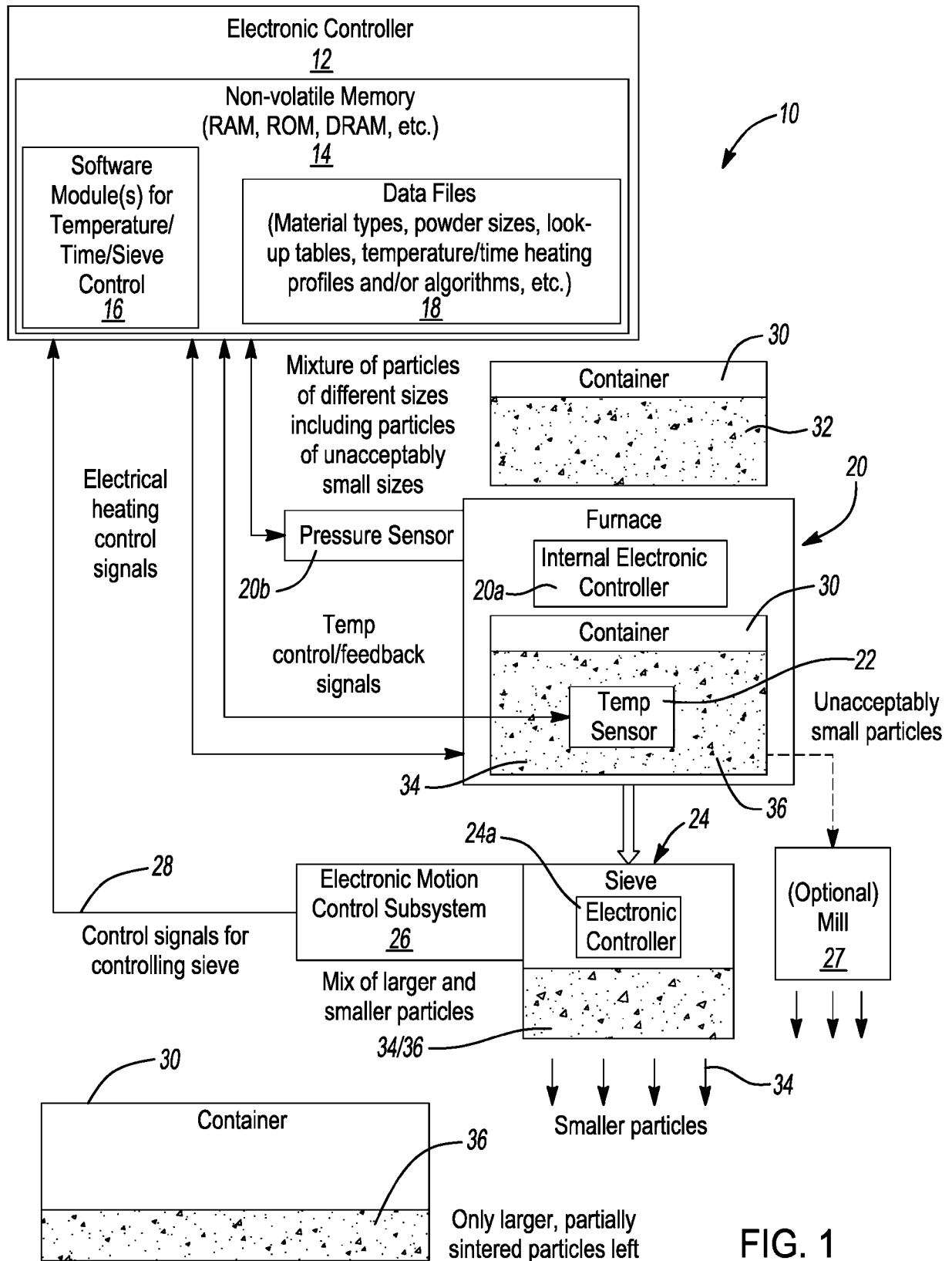
a mill controlled to further process the new plurality of powder particles to break down the new plurality of powder particles such that each one of the new of plurality of powder particles is reduced in dimensions to fall within the second distribution range.

18. The system of claim 17, wherein the electronic controller generates control signals for applying the predetermined, temperature/time heating profile to the heating component.

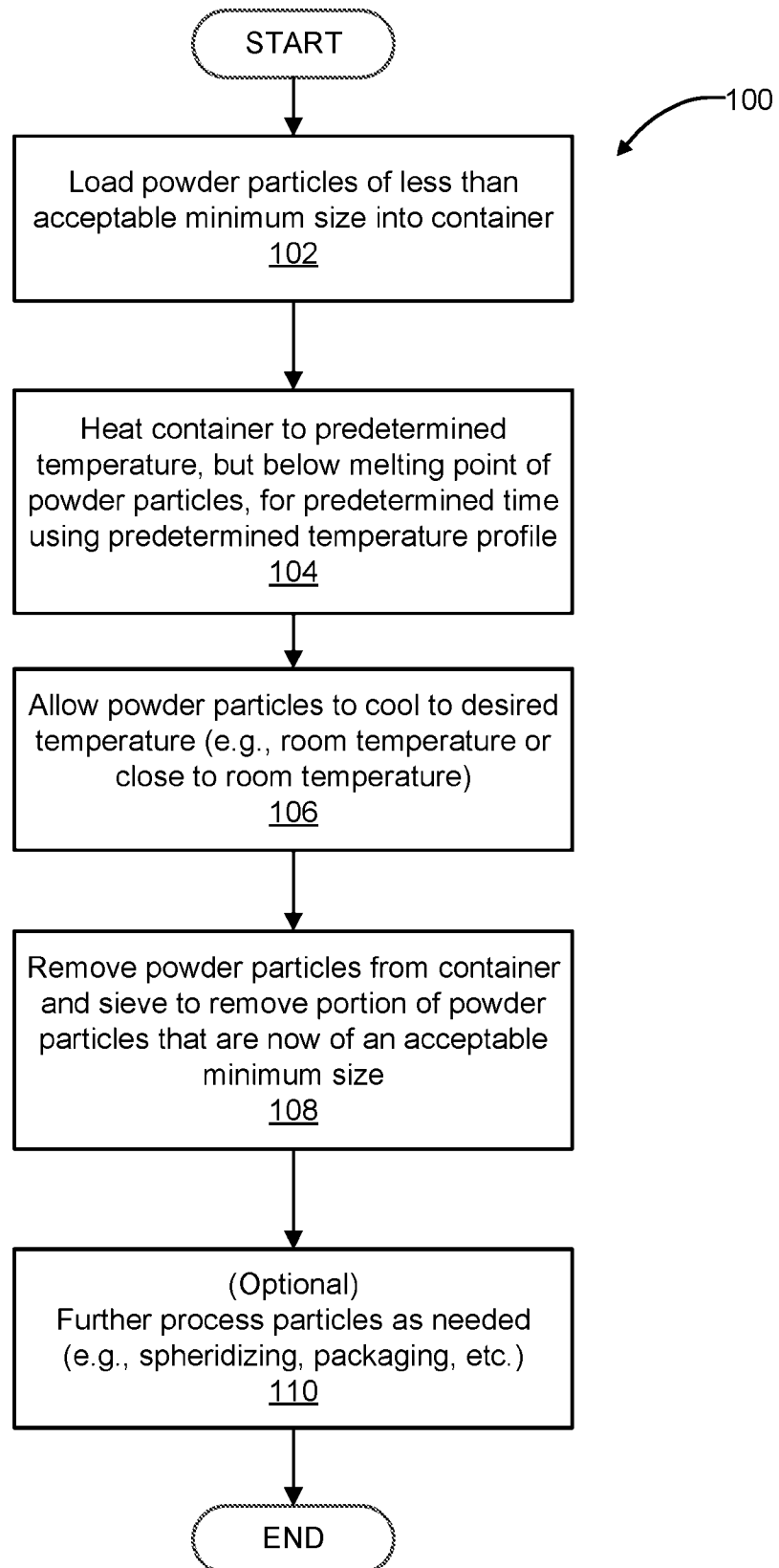
19. The system of claim 18, further comprising a memory in communication with the controller for storing the temperature/time heating profile.

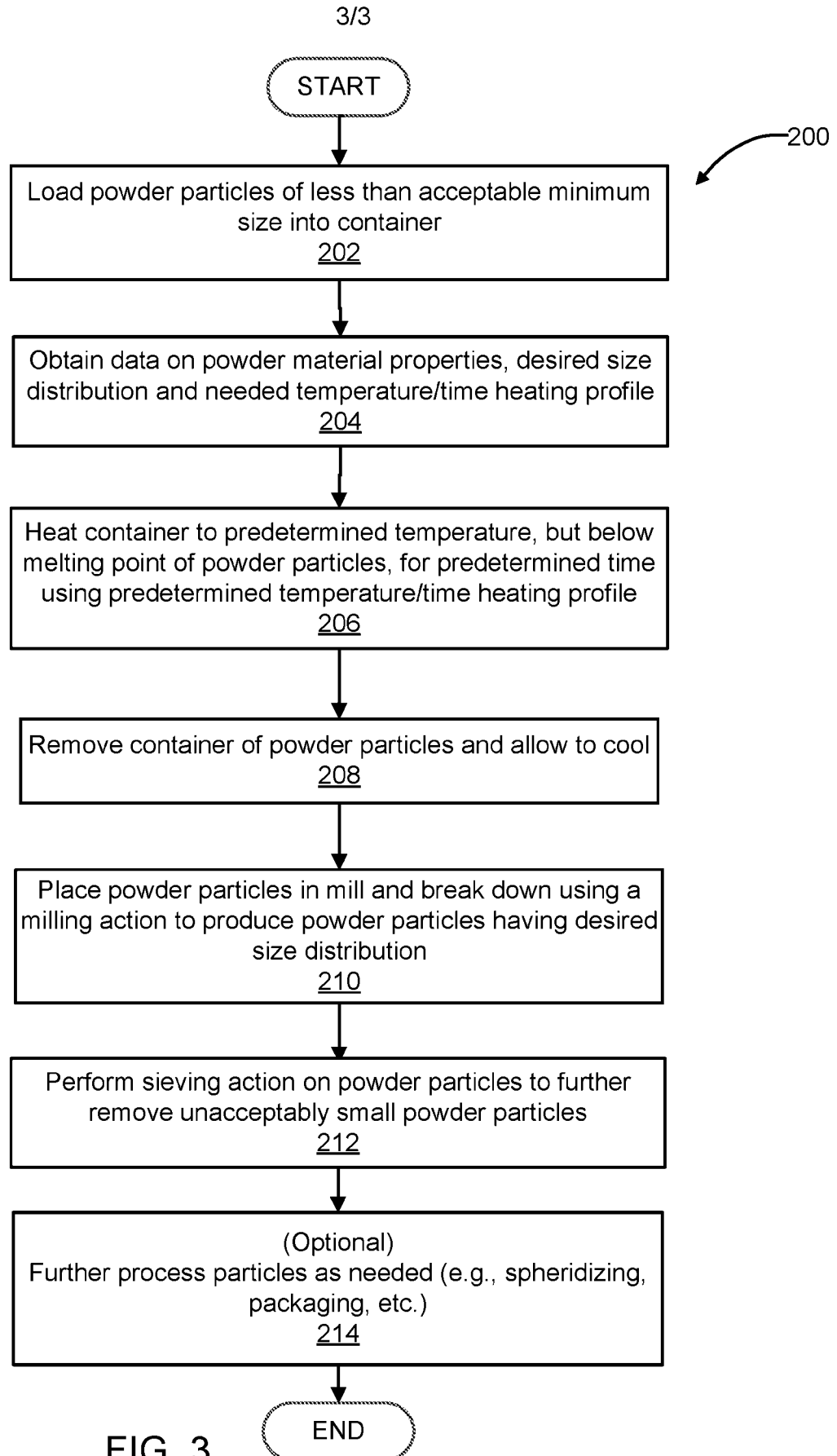
20. A method for creating a second quantity of sinterable powder particles which have sizes falling within a second size distribution range, from a first quantity of sinterable powder particles having sizes falling within a first size distribution range, and where the sizes of the powder particles in the second size distribution range are all larger than the sizes of the particles in the first size distribution range, the method comprising;

heating the first quantity of sinterable powder particles using a predetermined temperature/time heating profile sufficient to cause partial sintering of ones of the powder particles within the first quantity of sinterable powder particles, to create a new plurality of powder particles which have an increased dimension; and further processing the new powder particles such that the new plurality of powder particles represents the second quantity of sinterable powder particles.

**FIG. 1**

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FIG. 2

FIG. 3

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US2023/080050

A. CLASSIFICATION OF SUBJECT MATTER B22F 9/04(2006.01)i; B22F 1/068(2022.01)i; B33Y 70/00(2015.01)i According to International Patent Classification (IPC) or to both national classification and IPC		
B. FIELDS SEARCHED Minimum documentation searched (classification system followed by classification symbols) B22F 9/04(2006.01); B22F 3/10(2006.01); B22F 3/105(2006.01); B22F 9/08(2006.01); B22F 9/20(2006.01); C22C 1/04(2006.01); C22C 1/05(2006.01); G06N 20/00(2019.01) Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched Korean utility models and applications for utility models Japanese utility models and applications for utility models Electronic data base consulted during the international search (name of data base and, where practicable, search terms used) eKOMPASS(KIPO internal) & Keywords: powder, size, sieve, milling, memory		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2019-0001414 A1 (ELEMENT SIX G.M.B.H.) 03 January 2019 (2019-01-03) paragraphs [0048]-[0050] and figures 1, 3	1-20
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☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.		
* Special categories of cited documents: "A" document defining the general state of the art which is not considered to be of particular relevance "D" document cited by the applicant in the international application "E" earlier application or patent but published on or after the international filing date "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) "O" document referring to an oral disclosure, use, exhibition or other means "P" document published prior to the international filing date but later than the priority date claimed "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art "&" document member of the same patent family		
Date of the actual completion of the international search 12 March 2024		Date of mailing of the international search report 12 March 2024
Name and mailing address of the ISA/KR Korean Intellectual Property Office 189 Cheongsa-ro, Seo-gu, Daejeon 35208, Republic of Korea Facsimile No. +82-42-481-8578		Authorized officer PARK, Tae Wook Telephone No. +82-42-481-3405

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.

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