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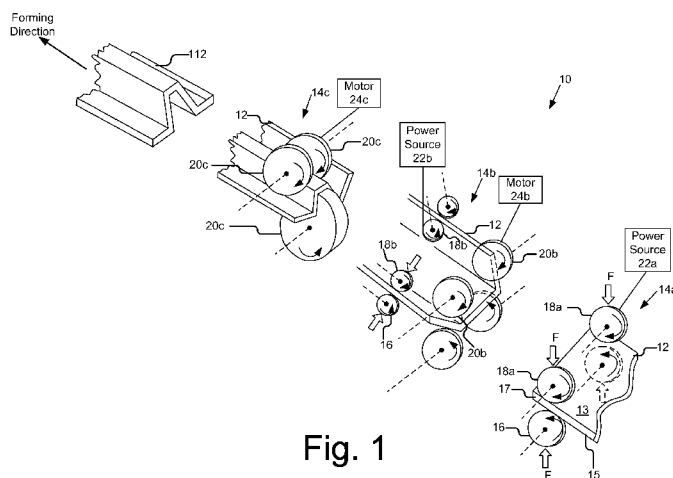


Fig. 1

(57) Abstract: A method of forming titanium structures, and more specifically, a method of superplastically continuous roll forming titanium structures are disclosed herein. In one embodiment, a method of forming a shape in an article (12) comprising titanium, the method including, among other things, providing first (18) and second (20) rolling members, the first rolling members (18) being conductive and the second rolling members (20) being continuous roll shaping members; contacting the article (12) with the first rolling members (18) to transfer a current to the article (12) to heat the article (12) to a temperature suitable for superplastic forming; and with the article (12) being in a superplastic state, contacting the article (12) with the second rolling members to form the shape in the article (12).

SUPERPLASTICALLY CONTINUOUS ROLL FORMING TITANIUM

FIELD OF THE INVENTION

The field of the present disclosure relates to a method of forming titanium structures, and more specifically, a method of superplastically continuous roll forming titanium structures.

BACKGROUND OF THE INVENTION

Superplastic forming (SPF) takes advantage of a material's superplasticity or ability to be strained past its rupture point under certain elevated temperature conditions and strain rates. Superplasticity in metals is defined by very high tensile elongations, ranging from two hundred to several thousand percent. SPF is a process that can be used to produce structures that takes advantage of the high elongation behavior of certain superplastic materials.

SPF typically includes the steps of heating a sheet of material to a point in which superplastic deformation is possible, clamping the material within a sealed die and then using gas pressure to force the material to stretch and take the shape of a forming surface located in the die cavity. Controlling the gas pressure during the forming process controls the deformation rate of the material and maintains superplasticity at the elevated temperature. Although desirable results have been achieved using such prior art methods, there is room for improvement. For example, it is known that prior art processes for SPF employing dies is limited to press size, a long heat up and cool down SPF cycle, thermal degradation of tools, and requirement for shielding gases to prevent alpha case build up or post SPF chemical process to remove alpha case. To that end, it may be desired to provide an improved method of SPF to form desired patterns in parts.

SUMMARY

The present invention is directed to a method of forming titanium structures employing superplastic continuous roll forming. Methods in accordance with the present invention may

advantageously reduce overall cycle time and alpha case build up, and may reduce the costs associated with forming titanium structures, in comparison with the prior art.

In one embodiment, a method includes forming a shape in an article comprising titanium, the method including, among other things, providing first and second rolling members, the first rolling members being conductive and the second rolling members being continuous roll shaping members. Next, the method includes contacting the article with the first rolling members to transfer a current to the article to heat the article to a temperature suitable for superplastic forming. Finally, with the article being in a superplastic state, contacting the article with the second rolling members to form the shape in the article.

In another embodiment, a part prepared by a process to form titanium comprising the steps of, among other things, applying a current to a titanium blank to heat the blank to a temperature suitable for superplastic forming. With the article being in a superplastic state, continuous roll forming the blank to form a shape therein to define the part.

The features, functions, and advantages that have been above or will be discussed below can be achieved independently in various embodiments, or may be combined in yet other embodiments, further details of which can be seen with reference to the following description and drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Embodiments of systems and methods in accordance with the teachings of the present disclosure are described in detail below with reference to the following drawings.

Fig. 1 is a simplified plan view of a system having a plurality of continuous rolling members to form a shape into a blank.

Fig. 2 is a flow chart showing a process of forming the shape in the blank using the system of Figure 1, in a first embodiment.

Figs. 3a-3e are plan views showing the blank being subjected to the process described in the first embodiment of Figure 2.

Figs. 4 and 5 are a flow chart showing a process of forming the shape in the blank using the system of Figs. 1 and 6-8, in a further embodiment.

Figs. 6-11 are plan views showing the blank being subjected to the process described in the further embodiment of Figures 4 and 5.

DETAILED DESCRIPTION

The present disclosure teaches a method of superplastically continuous roll forming titanium structures. Many specific details of certain embodiments of the invention are set forth in the following description and in Figures 1-11 to provide a thorough understanding of such embodiments. One skilled in the art will understand, however, that the invention may have additional embodiments, or that the invention may be practiced without several of the details described in the following description.

Referring to Fig. 1, a system 10 for forming a desired shape in a blank 12 is shown. Blank 12 may comprise first and second opposed sides 13 and 15 having a side surface 17 extending therebetween. Blank 12 may have a thickness of a magnitude of 0.063 to 0.375 inches, a width of a magnitude of 1 to 48 inches, and a length of a magnitude of 20 feet. In a further embodiment, blank 12 may comprise a coil that may be unrolled such that the same may be processed by system 10. Blank 12 may comprise a material selected from a group of materials including titanium and titanium alloys. By comprising one of the aforementioned materials, blank 12 may have a volume resistivity such that the same may be a poor conductor of electricity, and as a result, when current is applied thereto, a temperature of blank 12 may be increased, described further below. In an example, blank 12 may comprise a volume resistivity of approximately 80 micro ohm-cm.

System 10 comprises a plurality of stations 14 for forming a desired shape into blank 12, described further below. As shown, system 10 comprises three stations 14a, 14b, and 14c; however, system 10 may comprise any number of stations, depending upon the application desired and the shape desired to be formed into blank 12. To that end, each of stations 14 may facilitate forming a shape into blank 12 until a desired final shape of blank 12 is achieved. First

and second stations 14b and 14c may form a first and a second shape into blank 12, respectively, such that upon processing blank 12 by system 10, a final desired shape is formed into blank 12, shown as formed blank 112. To move blank 12 through system 10 and to and from each station 14, system 10 comprises a plurality of rolling members 16 that may be in contact with second side 15 of blank 12. The number of stationary rolling members 16 may depend on the number of stations 14 and the length of blank 12.

System 10 further comprises a plurality of first and second rolling members 18 and 20 positioned at stations 14. First rolling members 18 may be in electrical communication with a power source 22 such that first rolling members 18 may be conductive. For simplicity of illustration, each of first rolling members 18 may be in electrical communication with differing power sources 22; however, in a further embodiment, each of first rolling members 18 may be in electrical communication with the same power source 22. In an example, power source 22 may operate at 5 volts delivering 1500 amperes with a current density of 3000 amperes per square inch for blank 12. First rolling members 18 may transfer a current to blank 12 to heat blank 12, described further below. Second rolling members 20 may be in mechanical communication with a motor 24 such that each of second rolling members 20 may rotate in a desired motion such that when in contact with blank 12, second rolling members 20 may form a desired shape into blank 12, described further below. Further, second rolling members 20 may be substantially non-conductive or may be electrically isolated from the rest of system 10. For simplicity of illustration, each of second rolling members 20 may be in mechanical communication with differing motors 24; however, each of second rolling members 20 may be in mechanical communication with the same motor 24. First station 14a may comprise first rolling members 18a, second station 14b may comprise first and second rolling members 18b and 20b, and third station 14c may comprise second rolling members 20c.

To that end, system 10 forms a desired shape into blank 12 by moving blank 12 through system 10 and in superimposition with each of stations 14a, 14b, and 14c via mechanical rollers 16. Blank 12 may be continuously moved through system 10 such that blank 12 may be in superimposition with each of stations 14 successively, i.e. in order of first station 14a, second

station 14b, and third station 14c. In the present example, for simplicity of illustration, an entirety of blank 12 may be exposed to only one station of stations 14 at a time.

Referring to Figs. 2 and 3a, a first embodiment of a process of forming a desired shape into blank 12 by system 10 is described. Stationary rolling members 16 may move blank 12 such that blank 12 is in superimposition with first rolling members 18a. At first station 14a, first rolling members 18a may contact blank 12 on surface 13 thereof with a force F such that first rolling members 18a remain in contact with blank 12 to facilitate first rolling members 18a transferring a current to blank 12. In an example, force F may have a magnitude of up to several hundred pounds. To that end, upon transferring the current to blank 12, a temperature of blank 12 may be increased such that blank 12 may comprise a temperature suitable for superplastic forming, and, more specifically, in a range of approximately 1650° F -- 1750°F, shown at step 102. In a further embodiment, first rolling members 18a of first station 14a may contact any side of blank 12 in any configuration to facilitate transferring a current to blank 12. Further, in an example, blank 12 may comprise the temperature suitable for superplastic forming in an area approximately 4 to 48 inches in length across blank 12.

Referring to Figs. 2 and 3b, after placing blank 12 in a superplastic state, rolling members 16 may move blank 12 such that blank 12 may be in superimposition with second rolling members 20b of second station 14b. At second station 14b, second rolling members 20b may contact blank 12 to form a first shape thereinto, shown as step 104. As shown, second rolling members 20b contact first side 13 of blank 12; however, in a further embodiment, second rolling members 20b may contact blank 12 in any configuration (including any combination of first side 13, second side 15, and side surface 17) to form any desired shape into blank 12 at second station 14b. Furthermore, second rolling members 20b may have a temperature associated therewith that is less than the temperature associated with blank 12. In an example, the temperature of second rolling members 20 may have a magnitude in a range of approximately 200 °F up to 1750 °F for continuous rolling.

Referring to Figs. 2 and 3c, after forming the first shape into blank 12 at second station 14b, the temperature of blank 12 may decrease to a magnitude such that blank 12 may not be in a

superplastic state. As a result, the temperature of blank 12 may need to be increased. To that end, rolling members 16 may move blank 12 such that blank 12 is in superimposition with first rolling members 18b. First rolling members 18b may contact blank 12 to transfer the current to blank 12 to heat blank 12 to a temperature such that blank 12 may be in a superplastic state, shown as step 106. This process is substantially the same as described above with respect to first rolling members 18a of station 14a. To that end, in a further embodiment, first and second rolling members 18b and 20b may contact blank 12 concurrently, and in still a further embodiment, first rolling members 18b may contact blank 12 prior to second rolling members 20b contacting blank 12.

Referring to Figs. 2 and 3d, after placing blank 12 in a superplastic state at second station 14b, rolling members 16 may move blank 12 such that blank 12 may be in superimposition with third station 14c. At third station 14c, second rolling members 20c may contact blank 12 to form a second shape thereinto, shown as step 108. More specifically, the first shape of blank 12 formed at station 14b, mentioned above, may be transformed into the second shape at station 14c. To that end, the process of forming the second shape into blank 12 at third station 14c may be substantially the same as described above with respect to second rolling members 20b of second station 14b forming the first shape into blank 12. Further, as shown, second rolling members 20c contact first and second sides 13 and 15 of blank 12; however, in a further embodiment, second rolling members 20c of third station 14c may contact blank 12 in any configuration (including any combination of first side 13, second side 15, and side surface 17) to form any desired shape into blank 12 at third station 14c. Also analogous to that of second rolling members 20b, second rolling members 20c may have a temperature associated therewith that is less than the temperature associated with blank 12. To that end, system 10 has formed a final desired shape into blank 12, shown as formed blank 112 in Fig. 3e.

Referring to Figs. 1, 4, and 5, a further embodiment of the process of forming a desired shape into blank 12 by system 10 is described, the further embodiment comprising steps A)-F), described below. To that end, analogous to that mentioned above, first rollers 18a and 18b of first and second stations 14a and 14b, respectively, may contact any side of blank 12 in any

configuration to facilitate transferring a current to blank 12. Further, second rollers 20b and 20c of second and third stations 14b and 14c, respectively, may contact blank 12 in any configuration (including any combination of first side 13, second side 15, and side surface 17) to form any desired shape into blank 12. Also, first and second rolling members 18 and 20 may have a temperature associated therewith that is less than the temperature associated with a portion of blank 12 that is in a superplastic state. For ease of illustration, blank 12 is shown having multiple discrete portions. However, blank 12 may be a single continuous sheet.

A second embodiment of a process of forming a desired shape into blank 12 by system 10 is described below, comprising steps A – F.

Step A

Referring to Figs. 4 and 6, rolling members 16 may move blank 12 such that a first portion 40 of blank 12 is in superimposition with first rolling members 18a of first stations 14a.

At first station 14a, first rolling members 18a may contact blank 12 on surface 13 thereof with the aforementioned force F such that first rolling members 18a remain in contact with blank 12 to facilitate first rolling members 18a transferring a current to first portion 40 of blank 12. To that end, upon transferring the current to first portion 40 of blank 12, a temperature of first portion 40 of blank 12 may be increased such that first portion 40 of blank 12 may comprise a temperature suitable for superplastic forming, and, more specifically, in a range of approximately 1650° F -- 1750°F, shown at step 202.

Step B

Referring to Figs. 4 and 7, after completing step A), rolling members 16 may move blank 12 such that first portion 40 of blank 12 is in superimposition with second rolling members 20b of second station 14b and a second portion 42 of blank 12 is in superimposition with first rolling members 18a of first station 14a.

At second station 14b, second rolling members 20b may contact first portion 40 of blank 12 to form a first shape thereinto, shown at step 204.

At first station 14a, first rolling members 18a may contact second portion 42 of blank 12 on surface 15 thereof with the aforementioned force F such that first rolling members 18a remain in contact with second portion 42 of blank 12 to facilitate first rolling members 18a transferring a current to second portion 42 of blank 12. To that end, upon transferring the current to second portion 42 of blank 12, a temperature of second portion 42 of blank 12 may be increased such that second portion 42 of blank 12 may comprise a temperature suitable for superplastic forming, and, more specifically, in a range of approximately 1650° F -- 1750°F, shown at step 204.

Step C

Referring to Figs. 4 and 8, after completing step B), rolling members 16 may move blank 12 such that first and second portions 42 of blank 12 may be in superimposition with second rolling members 20b and first rolling members 18a, respectively, of second station 14b and a third portion 44 of blank 12 may be in superimposition with first rolling members 18a of first station 14a.

After forming the first shape into first portion 40 of blank 12 at second station 14b, the temperature of first portion 40 of blank 12 may decrease to a magnitude such that first portion 40 of blank 12 may not be in a superplastic state. As a result, the temperature of first portion 40 of blank 12 may need to be increased. To that end, first rolling members 18b may contact first portion 40 of blank 12 to transfer the current to blank 12 to heat first portion 40 of blank 12 to a temperature such that first portion 40 of blank 12 may be in a superplastic state, shown at step 206. This process is substantially the same as described above with respect to first rolling members 18a.

Concurrently, second rolling members 20b may contact second portion 42 of blank 12 to form a second shape thereinto, shown at step 206.

Concurrently, first rolling members 18a may contact blank 12 on surface 13 thereof with a force F_1 such that first rolling members 18a remain in contact with blank 12 to facilitate first rolling members 18a transferring a current to third portion 44 of blank 12. To that end, upon transferring current to third portion 44 of blank 12, a temperature of third portion 44 of blank 12

may be increased such that third portion 44 of blank 12 may comprise a temperature suitable for superplastic forming, and, more specifically, in a range of approximately 1650° F -- 1750°F, shown at step 206.

Step D

Referring to Figs. 5 and 9, after completing step C), rolling members 16 may move blank 12 such that first portion 40 of blank 12 may be in superimposition with second rolling members 20c of third station 14c and second and third portions 42 and 44 of blank 12 are in superimposition with first rolling members 18b and second rolling members 20b, respectively, of second station 14b.

Second rolling members 20c may contact first portion 40 of blank 12 to form a third shape thereinto. More specifically, the first shape of first portion 40 of blank 12 formed at station 14b, mentioned above, may be transformed into the third shape of first portion 40 of blank 12 at station 14c by second rolling members 20c, shown at step 208.

Concurrently, after forming the second shape into second portion 42 of blank 12 at second station 14b, the temperature of second portion 42 of blank 12 may decrease to a magnitude such that second portion 42 of blank 12 may not be in a superplastic state. As a result, the temperature of second portion 42 of blank 12 may need to be increased. To that end, first rolling members 18b may contact second portion 42 of blank 12 to transfer the current to blank 12 to heat second portion 42 of blank 12 to a temperature such that second portion 42 of blank 12 may be in a superplastic state, shown at step 208.

Concurrently, second rolling members 20b may contact third portion 44 of blank 12 to form a fourth shape thereinto, shown at step 208.

Step E

Referring to Figs. 5 and 10, after completing step D), rolling members 16 may move blank 12 such that second portion 42 of blank 12 may be in superimposition with second rolling

members 20c of third station 14c and third portion 44 of blank 12 is in superimposition with first rolling members 18b of second station 14b.

Second rolling members 20c may contact second portion 42 of blank 12 to form a fifth shape thereinto. More specifically, the second shape of second portion 42 of blank 12 formed at second station 14b, mentioned above, may be transformed into the fifth shape of second portion 42 of blank 12 at third station 14c by second rolling members 20c, shown at step 210.

Concurrently, the temperature of third portion 44 of blank 12 may decrease to a magnitude such that third portion 44 of blank 12 may not be in a superplastic state. As a result, the temperature of third portion 44 of blank 12 may need to be increased. To that end, first rolling members 18b may contact third portion 44 of blank 12 to transfer the current to blank 12 to heat third portion 44 of blank 12 to a temperature such that third portion 44 of blank 12 may be in a superplastic state, shown at step 210.

Step F

Referring to Figs. 5 and 11, after completing step E), rolling members 16 may move blank 12 such that third portion 44 of blank 12 may be in superimposition with second rolling members 20c of third station 14c.

Second rolling members 20c of third station 14c may contact third portion 44 of blank 12 to form a sixth shape thereinto. More specifically, the fourth shape of third portion 44 of blank 12 formed at second station 14b, mentioned above, may be transformed into the sixth shape of third portion 44 of blank 12 at third station 14c, shown at step 212. To that end, system 10 has formed a final desired shape into blank 12.

For simplicity of illustration, blank 12 is shown comprising three portions 40, 42, and 44. This is merely for ease of example of blank 12 being subjected to the process of system 10 and blank 12 may comprise any number of portions to form a desired shape therein. Furthermore, please note that system 10 is shown having a plurality of stations 14 for ease of understanding.

System 10 may have stations 14 arranged in any order and any configuration such that system 10 may to form a desired shape into blank 12.

Furthermore, blank 12 may be exposed to an environment within system 10 comprising oxygen. As a result, in temperatures above approximately 1000° F, blank 12 may absorb the oxygen resulting in alpha case build up within blank 12, which may undesirable. However, as mentioned above, any portion of blank 12 may be exposed to temperatures to place the same in a superplastic state for a limited period of time, and a result, alpha case build up within blank 12 may be minimized, if not prevented, which is desirable. In a further embodiment to minimize, if not prevent, alpha case build up within blank 12, blank 12 may be exposed to an environment within system 10 comprising an inert gas, such as argon.

While specific embodiments of the invention have been illustrated and described herein, as noted above, many changes can be made without departing from the spirit and scope of the invention. Accordingly, the scope of the invention should not be limited by the disclosure of the specific embodiments set forth above. Instead, the invention should be determined entirely by reference to the claims that follow.

What is claimed is:

1. A method of forming a shape in an article comprising titanium, the method comprising:
providing first and second rolling members, the first rolling members being conductive and the second rolling members being continuous roll shaping members;
contacting the article with the first rolling members to transfer a current to the article to heat the article to a temperature suitable for superplastic forming; and
with the article being in a superplastic state, contacting the article with the second rolling members to form the shape in the article.
2. The method as recited in claim 1, wherein providing further includes the second rolling member being non-conductive.
3. The method as recited in claim 1, wherein the temperature of the article is greater than a temperature associated with the second rolling members.
4. The method as recited in claim 1, wherein the article may have the temperature suitable for superplastic forming for a magnitude of time to minimize alpha case within the article.
5. The method as recited in claim 1 further comprising contacting the article with the first and second rolling members concurrently.
6. The method as recited in claim 1 further comprising contacting the article with the first rolling members prior to contacting the article with the second rolling members.
7. A part prepared by a process to form titanium comprising the steps of:
applying a current to a titanium blank to heat the blank to a temperature suitable for superplastic forming; and
with the article being in a superplastic state, continuous roll forming the blank to form a shape therein to define the part.

8. The part as recited in claim 7, wherein applying may further comprise heating the blank to the temperature suitable for superplastic forming for a magnitude of time to minimize alpha case within the blank.

9. The part as recited in claim 7, wherein the part is an airplane part.

10. A system for forming a shape in an article comprising titanium, the system comprising:

first conductive rolling members to transfer a current to the article to heat the article to a temperature suitable for superplastic forming; and

second continuous roll shaping members to form a shape into the article while the article is in a superplastic state.

11. The system as recited in claim 10, wherein providing further includes the second rolling member being non-conductive.

12. The system as recited in claim 10, wherein the temperature of the article is greater than a temperature associated with the second rolling members.

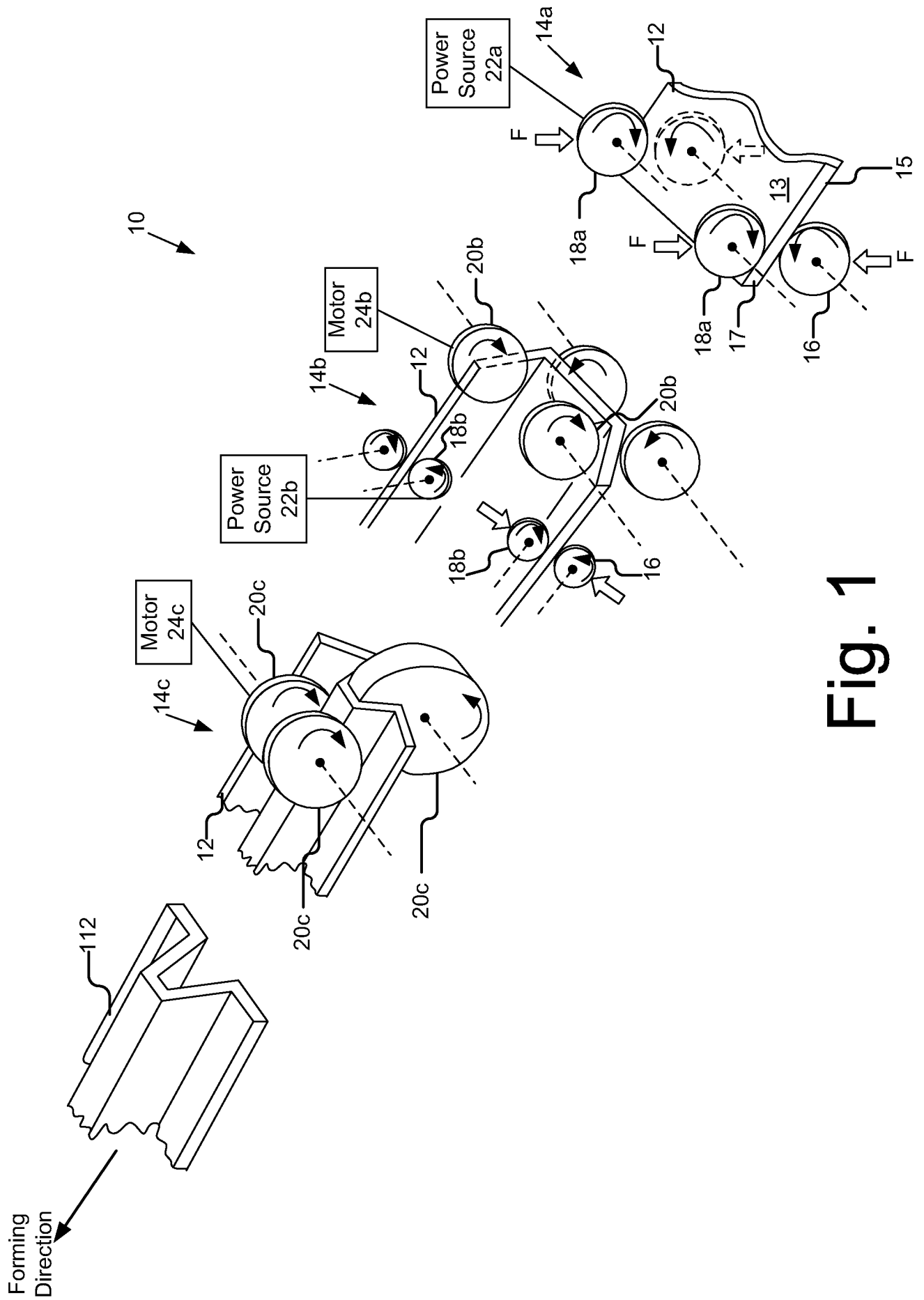
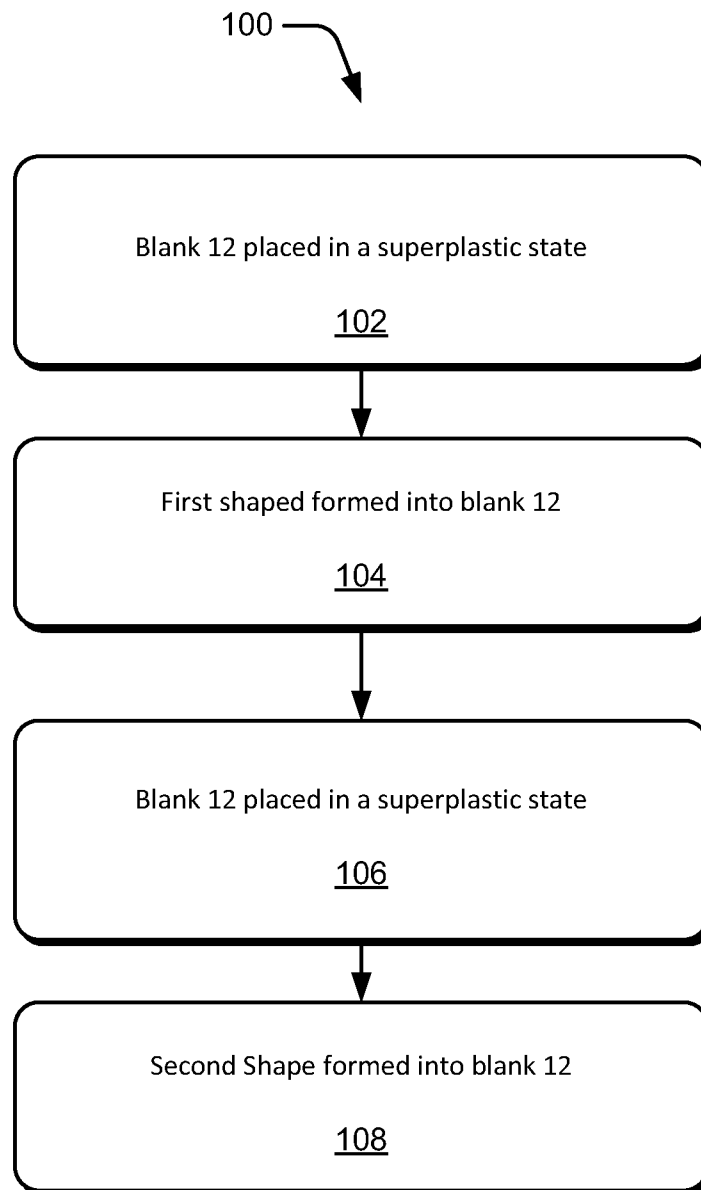
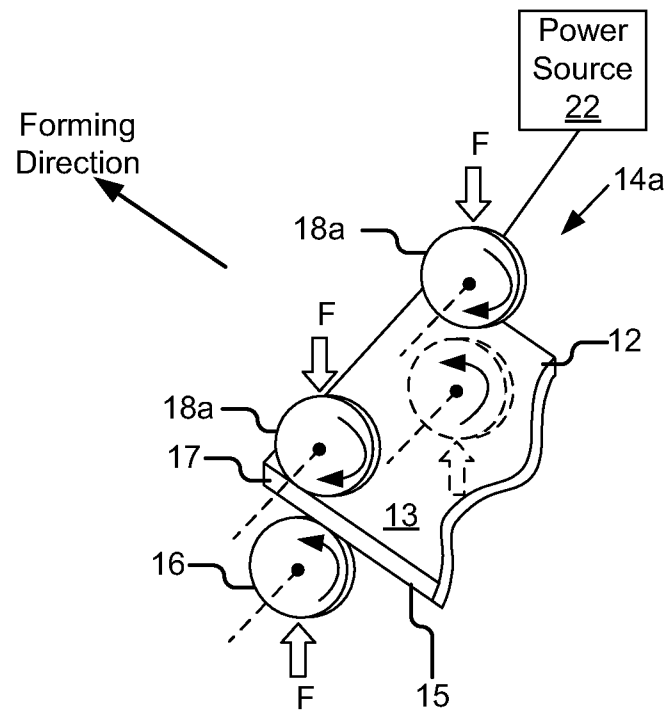
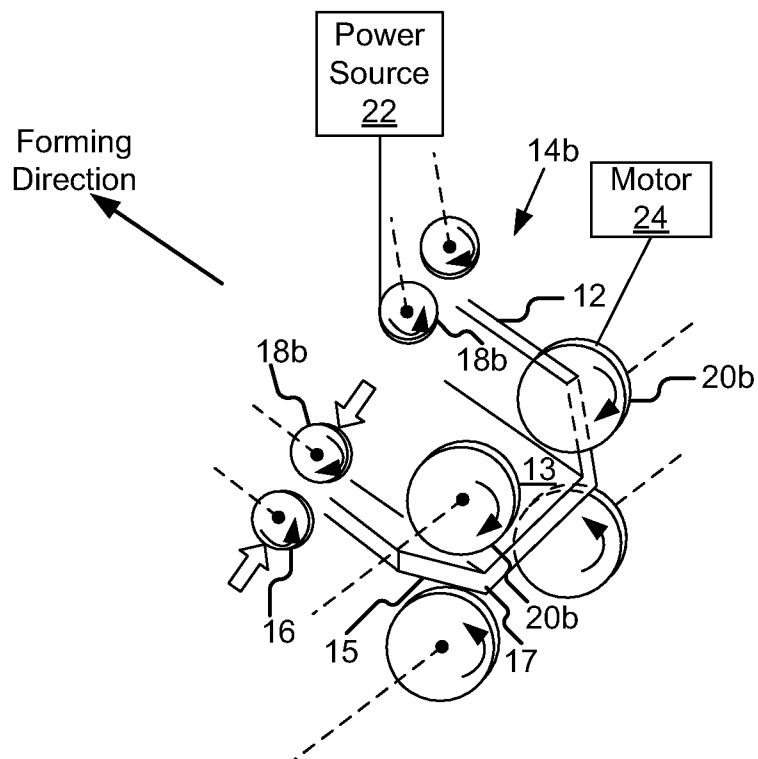
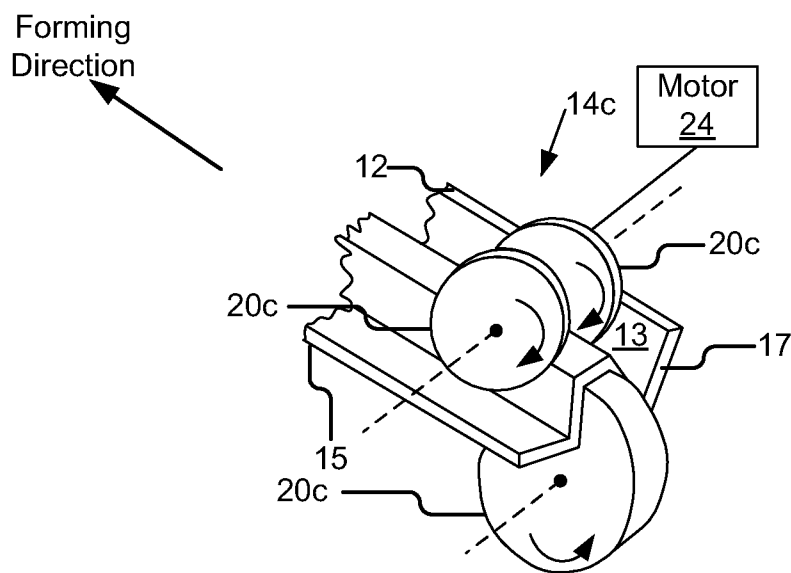
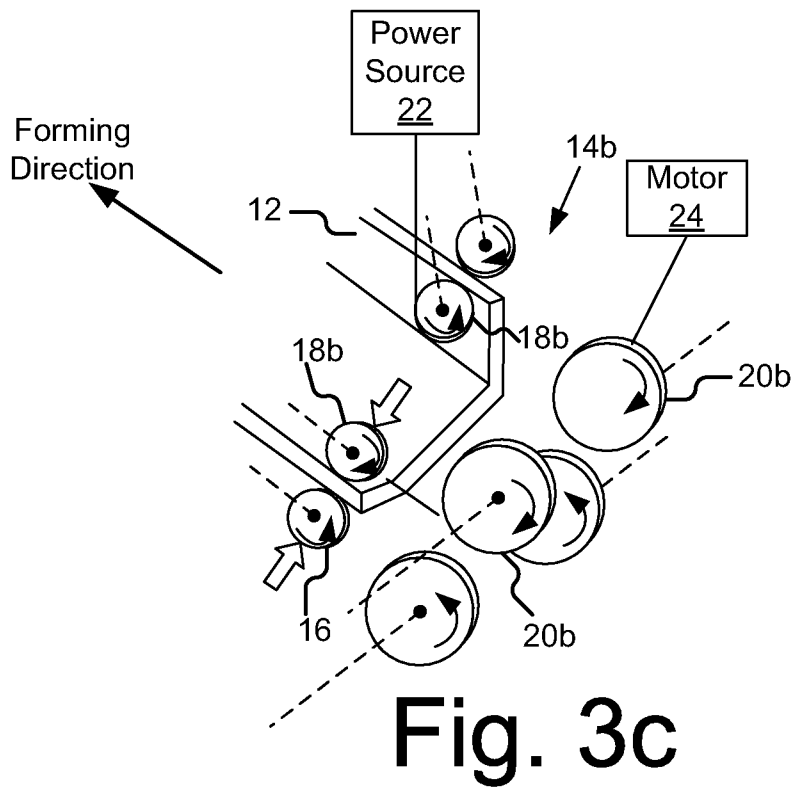


Fig. 1

**Fig. 2**

**Fig. 3a****Fig. 3b**



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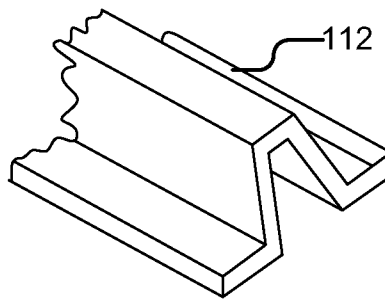
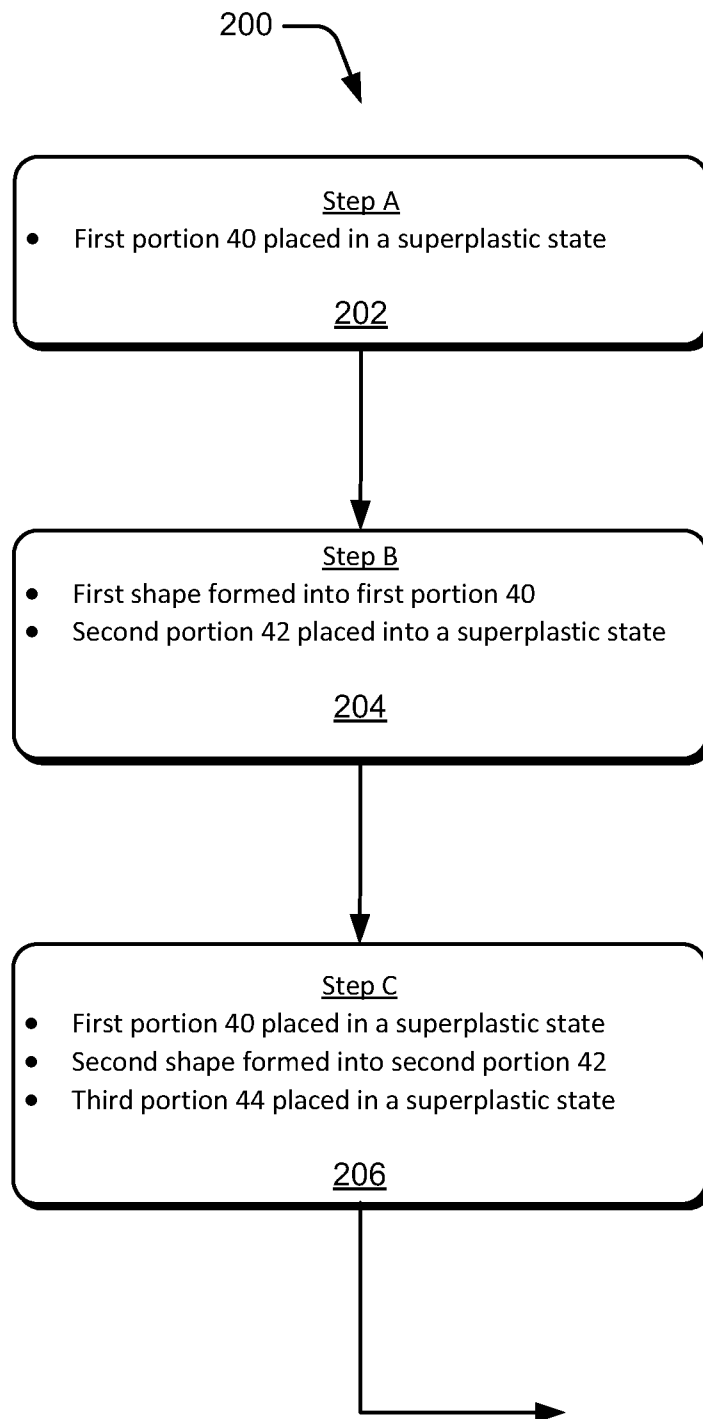


Fig. 3e

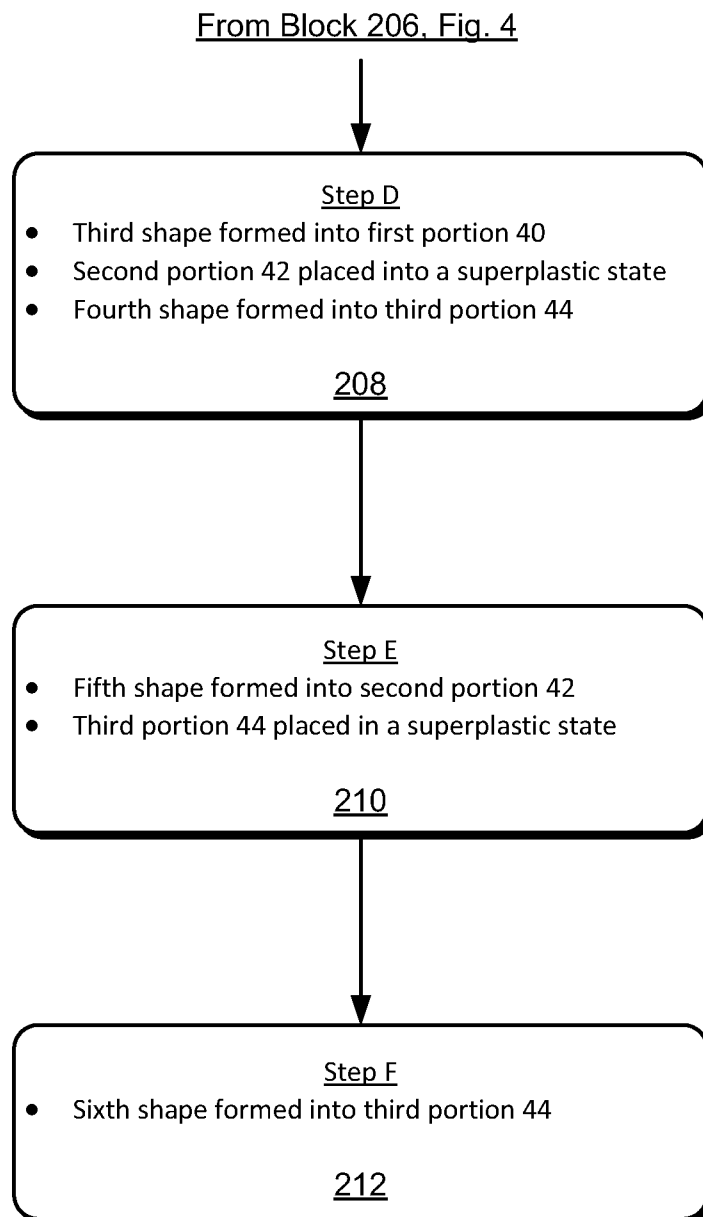
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To Block 208, Fig. 5

Fig. 4

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**Fig. 5**

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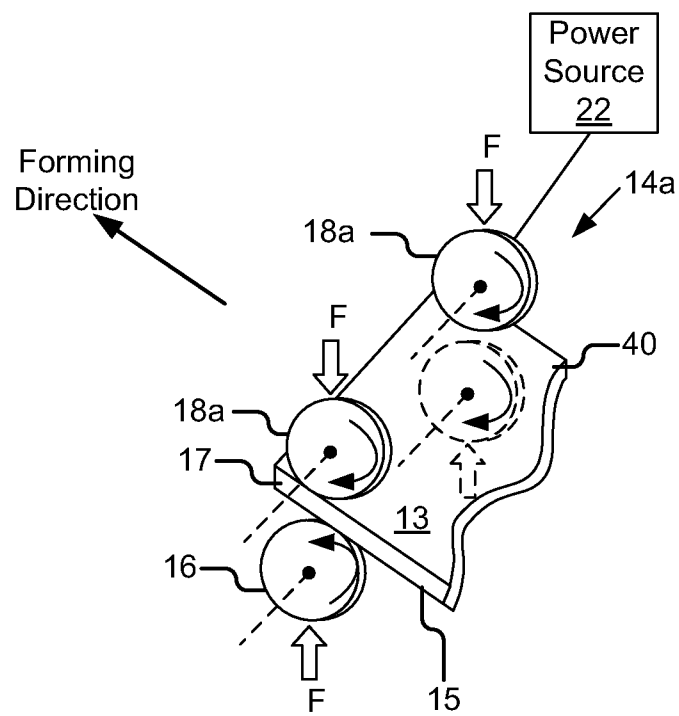


Fig. 6

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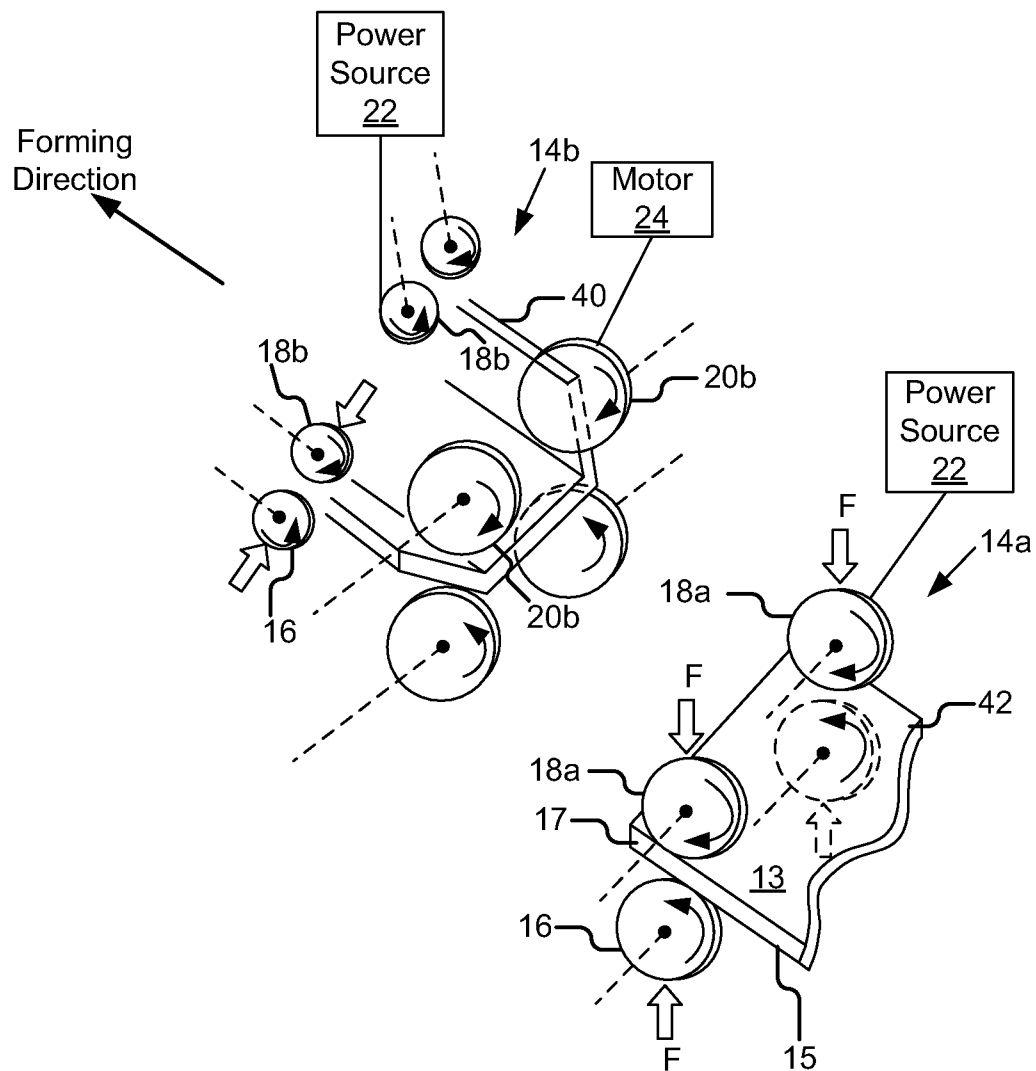
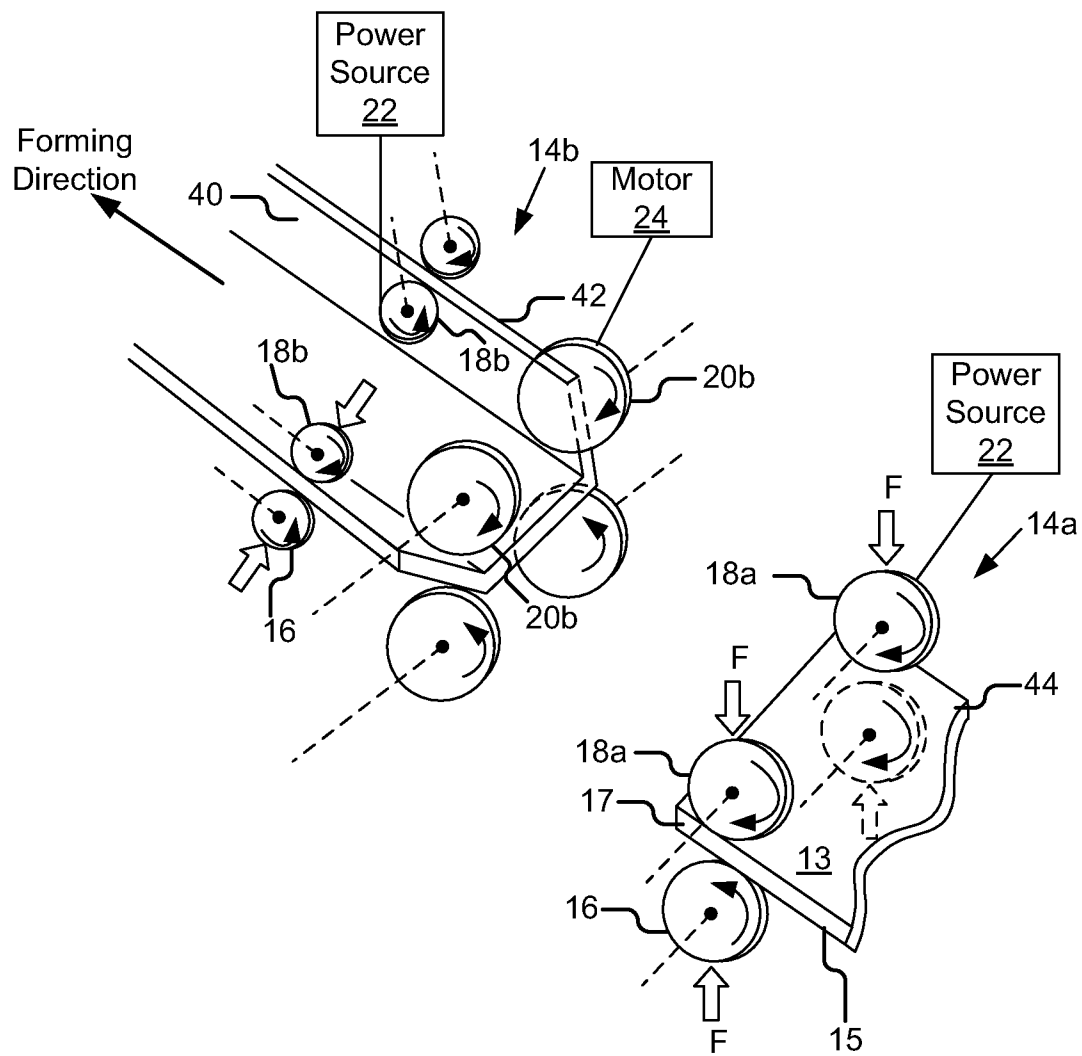


Fig. 7

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**Fig. 8**

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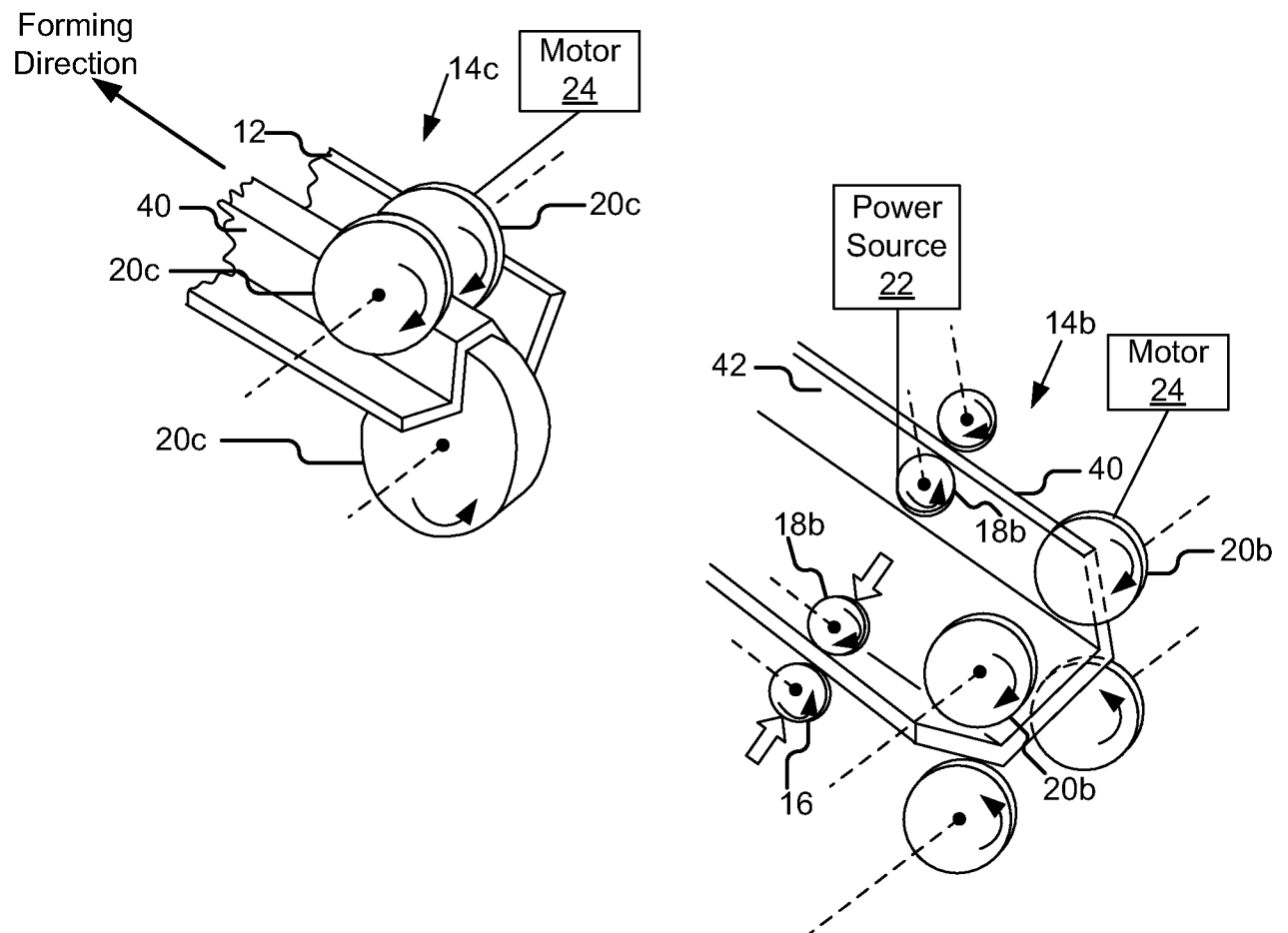


Fig. 9

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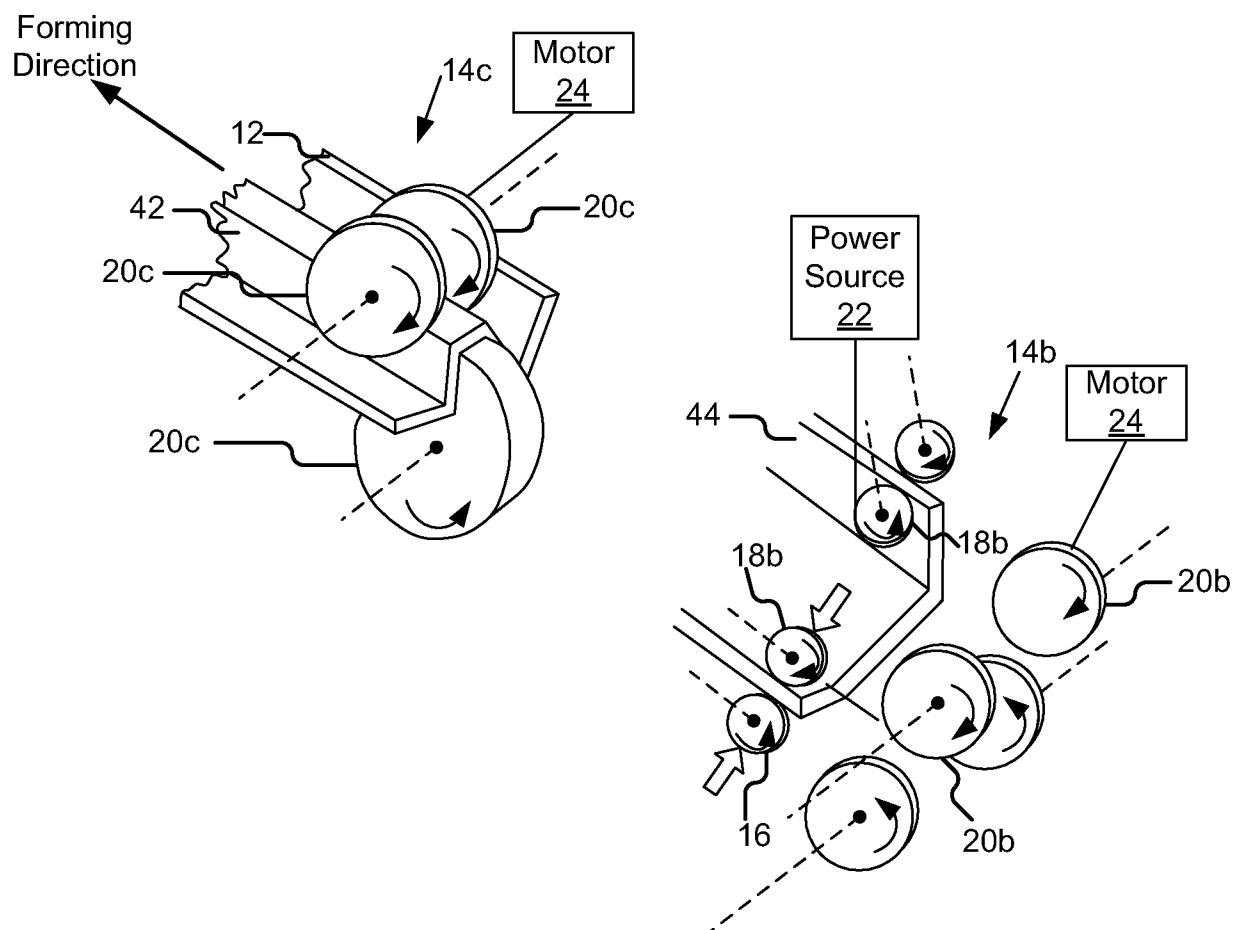


Fig. 10

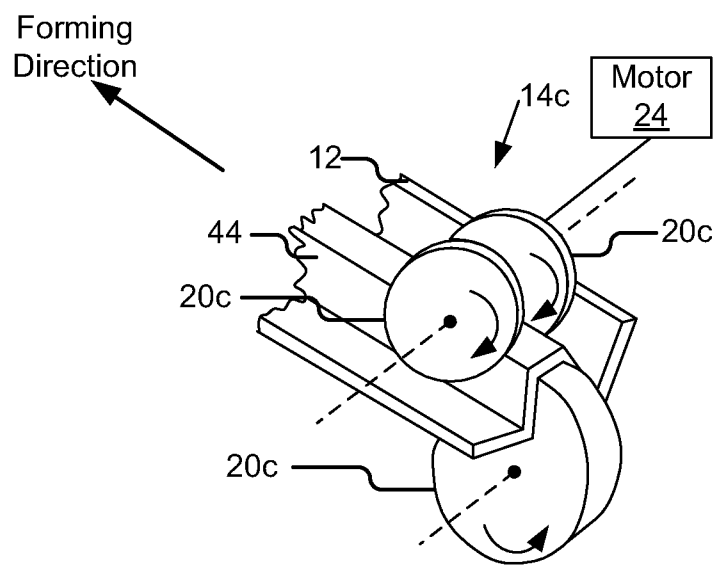


Fig. 11

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2009/055305

A. CLASSIFICATION OF SUBJECT MATTER
INV. B21D5/08

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)
B21D

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	GB 1 501 623 A (INT HARVESTER CO) 22 February 1978 (1978-02-22) page 3, line 72 - line 105 page 4, line 11 - line 18 page 13, line 104 - line 107 page 16, line 81 - line 115 page 11, line 66 - line 86; figures 1, 24A, 24B	1-12
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A	the whole document	1,10
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☒ Further documents are listed in the continuation of Box C.

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INTERNATIONAL SEARCH REPORT

International application No

PCT/US2009/055305

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