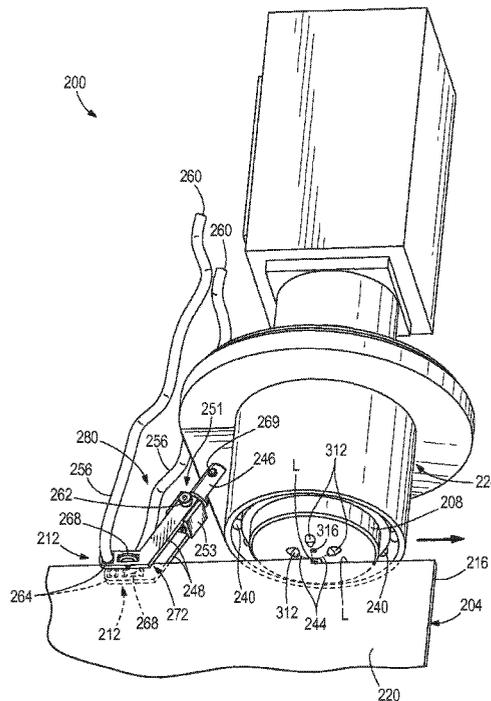




(86) **Date de dépôt PCT/PCT Filing Date:** 2014/06/24
 (87) **Date publication PCT/PCT Publication Date:** 2015/01/29
 (45) **Date de délivrance/Issue Date:** 2020/08/25
 (85) **Entrée phase nationale/National Entry:** 2015/11/05
 (86) **N° demande PCT/PCT Application No.:** US 2014/043833
 (87) **N° publication PCT/PCT Publication No.:** 2015/012992
 (30) **Priorité/Priority:** 2013/07/24 (US13/949,946)

(51) **Cl.Int./Int.Cl. B22F 3/105** (2006.01),
B22F 3/24 (2006.01), **B29C 64/153** (2017.01),
B29C 64/268 (2017.01), **B33Y 10/00** (2015.01),
B33Y 30/00 (2015.01)
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(54) **Titre : SYSTEMES, APPAREILS ET PROCEDES D'IMPRESSION EN TROIS DIMENSIONS**
 (54) **Title: ADDITIVE-MANUFACTURING SYSTEMS, APPARATUSES AND METHODS**



(57) **Abrégé/Abstract:**

An additive-manufacturing system comprises an additive-manufacturing head operable to deposit a new layer of material on an existing layer of material and melt the new layer of material to weld the new layer to the existing layer of material. A surface-processing device coupled to the additive-manufacturing head comprises a laser-emitting device configured to emit a laser beam that smooths adjacent surfaces of the new layer of material and the existing layer of material.

ABSTRACT

An additive-manufacturing system comprises an additive-manufacturing head operable to deposit a new layer of material on an existing layer of material and melt the new layer of material to weld the new layer to the existing layer of material. A surface-
5 processing device coupled to the additive-manufacturing head comprises a laser-emitting device configured to emit a laser beam that smooths adjacent surfaces of the new layer of material and the existing layer of material.

ADDITIVE-MANUFACTURING SYSTEMS, APPARATUSES AND METHODS
FIELD OF THE DISCLOSURE

The present disclosure generally relates to additive manufacturing and, more particularly, to processing surfaces of articles produced by additive manufacturing.

5

BACKGROUND

Additive manufacturing is utilized to fabricate 3-dimensional (3D) parts or products by adding layer-upon-layer of material. Additive manufacturing utilizes 3D-modeling (Computer-Aided Design or CAD) software, computer-controlled additive-manufacturing equipment, and raw materials in powder or liquid form. Additive manufacturing encompasses a wide variety of technologies and incorporates a wide variety of techniques, such as, for example, laser freeform manufacturing (LFM), laser deposition (LD), direct metal deposition (DMD), laser metal deposition, laser additive manufacturing, laser engineered net shaping (LENS), stereolithography (SLA), selective laser sintering (SLS), fused deposition modeling (FDM), multi-jet modeling (MJM), 3D printing, rapid prototyping, direct digital manufacturing, layered manufacturing, and additive fabrication. Moreover, a variety of raw materials may be used in additive manufacturing to create products. Examples of such materials include plastics, metals, concrete, and glass.

One example of an additive-manufacturing system is a laser additive-manufacturing system. Laser additive manufacturing includes spraying or otherwise injecting a powder or a liquid into a focused beam of a high-power laser or nexus of a plurality of high-powered lasers under controlled atmospheric conditions, thereby creating a weld pool. The resulting deposits may then be used to build or repair articles for a wide variety of applications. The powder injected into the high-power laser beam may be comprised of a wide variety of materials that include, for example, metal, plastic, etc.

Articles formed by additive manufacturing may require surface processing to provide a more desirable product. One example of surface processing includes smoothing or otherwise reducing the roughness of the product's surface. Surfaces produced by additive manufacturing may have rough surface finishes, e.g., on the order of about 600 – 1000 microinches R_a . Such rough surfaces may have several undesirable effects. For example, parts having a rough surface finish have limited applications in cyclical-loading environments due to stress risers typically associated with high surface roughness. Additionally, rough surfaces may impede the use of cost-saving, non-destructive inspection systems because rough surface finishes generate high

levels of noise in such systems. Examples of inspection systems include NDI, NDT, Die inspection, CAT scanning, X-ray, etc. When used on parts having relatively smooth surfaces, non-destructive inspection methods are widely recognized as cost-effective and accurate tools for identifying structural deficiencies in such parts.

5 To improve the surface finish of a part fabricated with additive-manufacturing equipment, separate post-processing steps must be undertaken at processing location using conventional surface-finishing equipment and techniques. However, due to the complexity of some parts, post-processing of surfaces thereof may be cumbersome, expensive, and time consuming. In addition, conventional post-processing surface-finishing methods may be
10 ineffective for reducing the surface roughness of the interior surfaces of some complex parts, resulting in products with less than desirable properties.

SUMMARY

It would be desirable to provide additive-manufacturing systems and apparatuses
15 therefor that process exterior and/or interior surfaces of manufactured parts in an efficient and cost-effective manner, and additionally are capable of processing surfaces of parts having complex configurations.

In one aspect of the disclosure, an additive-manufacturing system includes an additive-manufacturing head and a surface-processing device coupled to the additive-
20 manufacturing head.

In another aspect of the disclosure, a surface-processing apparatus for an additive-manufacturing head includes a housing configured to be coupled to the additive-manufacturing head and a surface-processing device coupled to the housing.

In a further aspect of the disclosure, a method of forming a product using an
25 additive-manufacturing head includes forming one or more layers of the product with the additive-manufacturing head and processing at least one of the one or more layers of the product with a surface-processing device coupled to the additive-manufacturing head.

In one embodiment, there is provided an additive-manufacturing system, including: an additive-manufacturing head, operable to deposit a new layer of material on an existing
30 layer of material and melt the new layer of material to weld the new layer of material to the existing layer of material; and a surface-processing device, coupled to the additive-

manufacturing head. The surface-processing device includes a laser-emitting device, configured to emit a first laser beam and a second laser beam that smooth, respectively, a first surface and a second surface of at least one of the new layer of material and the existing layer of material.

5 In another embodiment, there is provided a method of forming a product using an additive-manufacturing head. The method involves causing the additive manufacturing head to form one or more layers of the product and causing a first laser beam and a second laser beam to smooth, respectively, a first surface and a second surface of at least one of the one or more layers.

10 In another embodiment, there is provided an additive-manufacturing system including: an additive-manufacturing head; a surface-processing device coupled to the additive-manufacturing head; a support member coupled to the additive-manufacturing head; a laser energy source; and a laser-delivery device, including a first end, optically coupled to the laser energy source, and a second end, coupled to the support member. The surface-processing device includes a laser-emitting device configured to emit a first and a second laser beam arranged to smooth at least one of one or more layers produced by the additive-manufacturing system, along, respectively, an interior surface and an exterior surface of the one or more layers by melting a portion of the at least one of the one or more layers.

20 In another embodiment, there is provided a method of forming a product using an additive-manufacturing system described above or variants thereof. The method involves forming one or more layers of the product with the additive-manufacturing head and processing at least one of the one or more layers of the product with the surface-processing device. The surface-processing device includes the laser-emitting device configured to emit the first and the second laser beam. Processing the at least one of the one or more layers of the product involves smoothing the at least one of the one or more layers of the product along the interior surface and the exterior surface of the at least one of the one or more layers of the product by melting a portion of the at least one of the one or more layers of the product.

30 It should be understood that the specific examples herein are intended for purposes of illustration only and are not intended to limit the scope of the present disclosure.

BRIEF DESCRIPTION OF THE DRAWINGS

The disclosure can be better understood with reference to the following drawings and description. The components in the figures are not necessarily to scale, emphasis instead being placed upon illustrating the principles of the disclosure.

5 Fig. 1 is a flow diagram of an example of aircraft production and service methodology;

Fig. 2 is a block diagram of one example of an aircraft;

Fig. 3 is a bottom isometric view of one example of an additive-manufacturing system and a portion of one example of a part or product manufactured by the additive-
10 manufacturing system;

Fig. 4 is a top isometric view of a portion of the additive-manufacturing system shown in Fig. 3;

Fig. 5 is an elevational view of the additive-manufacturing system shown in Fig. 3;

Fig. 6 is a partially exploded view of the additive-manufacturing system shown in
15 Fig. 3;

Fig. 7 is a cross-sectional view taken along line 7—7 in Fig. 5;

Fig. 8 is one example of a block diagram of the additive-manufacturing system shown in Fig. 3;

Fig. 9 is an enlarged view of one example of a pair of surface-processing devices
20 configured to process surfaces of a product;

Fig. 10 illustrates examples of a plurality of shapes that the laser beam may comprise;

Fig. 11 illustrates a plurality of laser beams having a variety of different sizes;

Fig. 12 is a top isometric view of another example of an additive-manufacturing
25 system;

Fig. 13 is one example of a block diagram of the additive-manufacturing system shown in Fig. 12;

Fig. 14 is an elevational view of a portion of the additive-manufacturing system shown in Fig. 12;

30 Fig. 15 is an elevational view of a portion of the additive-manufacturing system shown in Fig. 12;

Fig. 16 is one example of a block diagram of a further example of an additive-manufacturing system; and

Fig. 17 is one example of a block diagram of another example of a surface processing apparatus.

5

DETAILED DESCRIPTION

Referring more particularly to the drawings, embodiments of the disclosure may be described in the context of an aircraft manufacturing and service method **100** as shown in Fig. 1 and an aircraft **102** as shown in Fig. 2. During pre-production, method **100** may include specification and design **104** of the aircraft **102** and material procurement **106**. During production, component and subassembly manufacturing **108** and system integration **110** of the aircraft **102** takes place. Thereafter, the aircraft **102** may go through certification and delivery **112** in order to be placed in service **114**. While in service by a customer, the aircraft **102** is scheduled for routine maintenance and service **116** (which may also include modification, reconfiguration, refurbishment, and so on).

Each of the processes of method **100** may be performed or carried out by a system integrator, a third party, and/or an operator (e.g., a customer). For the purposes of this description, a system integrator may include without limitation any number of aircraft manufacturers and major-system subcontractors; a third party may include without limitation any number of vendors, subcontractors, and suppliers; and an operator may be an airline, leasing company, military entity, service organization, and so on.

As shown in Fig. 2, the aircraft **102** produced by method **100** may include an airframe **118** with a plurality of systems **120** and an interior **122**. Examples of high-level systems **120** include one or more of a propulsion system **124**, an electrical system **126**, a hydraulic system **128**, and an environmental system **130**. Any number of other systems may be included. Although an aerospace example is shown, the principles of the present disclosure may be applied to other industries, such as the automotive industry or other industries.

Apparatus and methods embodied herein may be employed during any one or more of the stages of the production and service method **100**. For example, components or subassemblies corresponding to production process **108** may be fabricated or manufactured

in a manner similar to components or subassemblies produced while the aircraft **102** is in service. Also, one or more apparatus embodiments, method embodiments, or a combination thereof may be utilized during the production stages **108** and **110**, for example, by substantially expediting assembly of or reducing the cost of an aircraft **102**. Similarly, one
5 or more of apparatus embodiments, method embodiments, or a combination thereof may be utilized while the aircraft **102** is in service, for example and without limitation, to maintenance and service **116**.

Referring now to Figs. **3-11**, an example of an additive-manufacturing system **200** is illustrated and is configured to form a part or product **204** (see Fig. **3**), which may be
10 utilized in a variety of industries including, but not limited to, aerospace, automotive, etc. The additive-manufacturing system **200** is configured to create a wide variety of products **204**, having different shapes and sizes, as well as various levels of complexity. Products **204** may be made of a variety of materials including, but not limited to, metal, titanium alloys, nickel based alloys (Inconels), stainless and alloy steels, cobalt based alloys, plastic,
15 polymers, ultem, nylon, etc.

The additive-manufacturing system **200**, according to one or more aspects of the present disclosure, is capable of comprising a wide variety of additive-manufacturing equipment. In the illustrated system, the system **200** includes laser additive-manufacturing equipment. Other examples of a system of the present disclosure may incorporate
20 alternative additive-manufacturing equipment such as, for example, fused-deposition modeling (FDM), multi-jet modeling (MJM), 3D-printing, rapid-prototyping, direct digital manufacturing, layered-manufacturing, and additive-fabrication equipment. The illustrated additive-manufacturing equipment and the recitation of other examples of additive-manufacturing equipment herein are not intended to be limiting upon the present disclosure
25 in any way. Rather, the illustrated and described additive-manufacturing equipment is intended to demonstrate principles of the present disclosure. The additive-manufacturing system **200** is capable of including any type of additive-manufacturing equipment.

Referring, for example, to Fig. **16**, the additive-manufacturing system **200** includes an additive-manufacturing head **208** and a surface-processing device **212** coupled to the
30 additive-manufacturing head **208**. As shown, for example, in Fig. **3**, the system **200** may include two surface-processing devices **212** for processing two surfaces **216**, **220** of a

product **204** formed by the additive-manufacturing head **208**. Surfaces **216**, **220** may be, for example, an interior and an exterior surface, respectively. As mentioned with reference to Fig. **16**, the system **200** may also be configured to include a single surface-processing device **212** for treating a single surface of a product formed by the additive-manufacturing head **208**. Still further, the system **200** may include more than two surface-processing devices **212** for treating any number of surfaces **216**, **220** of a product **204** formed by the additive-manufacturing head **208**. In the illustrated system **200**, the two surface-processing devices **212** are substantially similar in structure and function. In other examples of the system **200**, the system may include two or more surface-processing devices **212** and such devices may be different in structure and function. The description herein and the associated figures include two similar surface-processing devices **212**, having similar structure and function. Such description and figures are not intended to be limiting, but are provided to demonstrate that many alternatives of the various aspects of the present disclosure are possible.

With reference to the illustrated system **200** in Figs. **3-11**, the two surface-processing devices **212** are similar in structure and function. Thus, only one of the surface-processing devices **212** will be described in more detail. The surface-processing device **212** is configured to smooth a surface of a product formed by the additive-manufacturing head **208**. In other words, the surface-processing device **212** is configured to reduce the roughness of a surface of a product formed by the additive-manufacturing head **208**. The surface-processing device **212** is movably coupled to the additive-manufacturing head **208**. The surface-processing device **212** may also be rotatably coupled to the additive-manufacturing head **208**. The surface-processing device **212** may be coupled to the additive-manufacturing head **208** in a variety of ways. The additive-manufacturing system **200** also includes a housing **224**, rotatably coupled to the additive-manufacturing head **208**. The surface-processing device **212** is coupled to the housing **224**. The housing **224** is configured to rotate about a virtual longitudinal central axis **228** (Fig. **5**), extending longitudinally and centrally through the additive-manufacturing head **208**. As shown, for example, in Fig. **8**, the system **200** may include means **328** for rotatably positioning the housing **224** relative to the additive-manufacturing head **208**. In one aspect, the means **328** may be a servo-motor coupled to the housing **224**. Referring, once again, to Fig. **3**, the housing **224** may be rotatably coupled to the additive manufacturing head via, e.g., ball bearings **240** between the

additive manufacturing head **208** and the housing **224**. In one example, the means **328** may be coupled to the housing **224** for rotatably positioning the housing **224** relative to the manufacturing head **208**.

5 With reference to, for example, Figs. **3** and **5**, the surface-processing device **212** has a trailing orientation relative to the additive-manufacturing head **208** as the head **208** moves relative to the product **204** being formed. The means **328** rotatably positions the housing **224** relative to the additive-manufacturing head **208** so that the surface-processing device **212** is in the trailing orientation relative to the additive-manufacturing head **208**. The surface-processing device **212** processes the product in-situ as the product is being formed
10 by the additive-manufacturing head **208**.

In the system **200** illustrated in Figs. **3-11**, the surface-processing device **212** is a laser-emitting device **212** configured to emit a laser beam **244** (Fig. **9**). The system **200**, illustrated, e.g., in FIG. **3**, further includes support members **248**, a laser energy source **252** (Fig. **8**), and laser-delivery devices **256**, including first ends **260**, optically coupled to the
15 laser energy source **252**, and second ends **264**, coupled to the support members **248**. According to one aspect of the disclosure, the laser-emitting device **212** may be the second end **264** of the laser-delivery device **256**. In one example, the second end **264** of the laser-delivery device **256** is configured to be generally polygonal in shape to emit the laser beam **244** having a generally polygonal cross-section.

20 In one example, the second end **264** of the laser-delivery device **256** is coupled to the laser-emitting device **212** that is polygonal in shape to emit the laser beam **244**, having a generally polygonal cross-section. In one variant, the laser-emitting device **212** may be rectangular in shape to emit the laser beam **244**, having a generally rectangular cross-section. Rectangular shapes include square shapes. In some aspects of the system **200**, for
25 example, when the laser-emitting device **212** is rectangular in shape, the laser beam **244** applies a constant quantity of energy to a surface of a product along the entire dimension H (see, for example, Figs. **10** and **11**) of the laser beam **244**, as the laser beam impinges the surface being processed. The above-described configuration of the laser beam ensures that the surface of the product being impinged by the laser beam is evenly processed along the
30 entire dimension H of the laser beam (e.g., evenly smoothed). Some examples of shapes of laser beams **244** that enable even processing of the product surface along the entire

dimension H of the laser beam impinging the surface being processed include, but are not limited to, square, rectangular, or any other shape having an equal dimension W along its entire dimension H.

With reference to, for example, Fig. 10, in other examples of the system, the laser-emitting device 212 is configured to emit the laser beam 244 having a generally arcuately perimetered shape. In further examples of the system, the laser-emitting device 212 is configured to emit the laser beam 244 having a generally circular shape. When the system is configured to emit the laser beam 244 having a generally arcuately perimetered shape, such an arcuately perimetered shape may be any shape having an at least partially arcuate perimeter. Some examples of arcuately perimetered shapes include, but are not limited to, a circle, a semi-circle, a hemi-circle, an oval, or a non-uniform shape. It should be understood that the laser-emitting device 212 is capable of emitting laser beams 244 having any shape (see Fig. 10).

Referring, e.g., to Fig. 8, the laser-delivery device 256 is optically coupled to the laser source 252 and the laser-emitting device 212. In the illustrated system illustrated in Figs 3-9, the laser-delivery device 256 may be a fiber optic cable 256. As shown, e.g., in Fig. 3, the system 200 includes two laser-delivery devices 256. The system 200 may include any number of laser-delivery devices 256 to communicate the laser beam(s) 244 from the laser energy source 252 to the laser-emitting devices 212. In other examples, the laser-delivery device 256 may be other devices configured to optically communicate the laser beam 244 from the laser source 252 to a surface of the product formed by the additive-manufacturing head 208. Some examples include, but are not limited to, mirrors, other light and energy reflective members, light guides, etc. The laser-emitting device 212 is configured to be spaced-apart from a surface of the product formed by the additive-manufacturing head 208. The additive-manufacturing system 200 further includes a guide member 268 configured to engage a product formed by the additive-manufacturing head 208 to orient the surface-processing device 212 relative to the product. The guide member 268 spaces the surface-processing device 212 a distance away from the surface of the product. In the illustrated system 200, the guide member 268 is a guide roller 268. In other examples of systems, the guide member 268 may be other types of guide members such as, for

example, a surface-tracking shoe that engages and slides against the surface of the product, or any other type of guide member.

The additive-manufacturing head **208** is configured to form a product from a plurality of layers L (see, for example, Figs. **3** and **9**). The surface-processing device **212** is configured to process the product formed by the additive-manufacturing head **208** in a variety of ways. In one aspect, the surface-processing device **212** is configured to process one of the plurality of layers L (see, for example, Fig. **9**). In another aspect, the surface-processing device **212** is configured to contemporaneously process two or more of the plurality of layers L. The surface-processing device **212** may be configured to contemporaneously process a number of layers L. With reference to Fig. **11**, various sizes of rectangular-shaped cross-sections of the laser beam **244** are shown to illustrate the ability to process a number of the layers L of a product formed by an additive-manufacturing head **208**. The laser beam **244** of any shape may have a variety of different sizes to process various numbers of layers of a product.

As indicated above, the surface-processing device **212** is configured to move relative to the additive-manufacturing head **208**. With reference to Fig. **5**, the surface-processing device **212** is configured to move relative to the additive-manufacturing head **208** between a first (or active) position, in which the surface-processing device **212** is capable of processing the product formed by the additive-manufacturing head **208**, and a second (or idle) position, in which the surface-processing device **212** is not capable of processing the product. In the illustrated system **200**, the surface-processing device **212** is rotatably coupled to the housing **224** and the surface-processing device **212** rotates between the first position and the second position. With continued reference to Fig. **5** and additional reference to Figs. **3**, **4**, **6**, and **7**, the system **200** includes a shaft **269**, having a virtual longitudinal central axis **270**. The surface-processing device **212** is configured to rotate about the shaft **269** and the associated longitudinal central axis **270** between the first position and the second position. Alternatively, the surface-processing device **212** may be coupled to the additive-manufacturing head **208** using any number of different methodologies and may move between the first position and the second position in a variety of different ways.

With continued reference to Figs. **3-7**, the system **200** also includes a coupling member **246** and a support member **248**. The coupling member **246** is coupled to and

between the housing **224** and the support member **248**, and the support member **248** supports the surface-processing device **212**. The support member **248** is configured to rotate relative to the coupling member **246** about a virtual longitudinal central axis **247** (Fig. **6**) of the coupling member **246**. The system **200** further includes a base **253** defining a first aperture **254** for receiving the coupling member **246**, a second aperture **255** generally orthogonal to the first aperture **254**, and a pair of recesses or channels **257** defined in opposing surfaces of the base for receiving respective support members **248**. A snap ring **258** couples the base **253** to the coupling member **246**. Ends of the support members **248** include counter-bored apertures **259** therein. The system **200** also includes means **251** for adjusting forces applied to surfaces of a product by the guide members **268**. The guide members **268** are preloaded against the surfaces of the product to maintain constant spacing of the surface-processing devices **212** relative to the surfaces of the product. In one example, the means **251** for adjusting preload include biasing members **261**, such as coil springs, positioned within the counter-bored apertures **259** and fasteners **262** extending through the biasing members **261** and the counter-bored apertures **259**. The fasteners **262** thread into the second aperture **255** of the base **253**. The coupling member **246** defines an opening or slots **263** therein to allow rotation of the base **253** relative to the coupling member **246** about the axis **247**. Thus, the base **253**, the biasing members **261**, the fasteners **262**, the support members **248**, and the surface-processing devices **212** rotate as a unit relative to the coupling member **246** about the axis **247**. Fasteners **262** can be tightened or loosened to adjust the force on the guide members **268** and their preload against the surfaces **216**, **220** of the product **204** by compressing the springs **261** or by allowing the springs to relax, respectively. The opening or slots **263** may be defined a portion of the way through the coupling member **246** or may be defined all the way through the coupling member **246**. Defining the opening or slots **263** either partially through or completely through the coupling member **246** may provide clearance between the fasteners **262** and the coupling member **246** and facilitate rotation of the fasteners **262** relative to the coupling member **246**.

In one aspect, the surface-processing device **212** is configured to rotate about at least one axis. The at least one axis may be any one or more of the axes **228**, **247**, **270** (see Figs. **5-7**). In another aspect, the surface-processing device **212** is configured to rotate about at least two axes. The at least two axes may be any two or more of the axes **228**, **247**, **270** (see

Figs. 5-7). In a further aspect, the surface-processing device **212** is configured to rotate about three axes. The three axis include all three axes **228, 247, 270** (see Figs. 5-7).

Referring now to Figs. 3-9, the system **200** is configured to include multiple surface-processing devices **212**, as indicated above. In one aspect of the system **200**, the surface-processing device **212** comprises a first surface-processing device **212** and a second surface-processing device **212**, spaced-apart from the first surface-processing device **212**. As shown, e.g., in Fig. 4, a space **272** is provided between the first and second surface-processing devices **212**. The first surface-processing device **212** and the second surface-processing device **212** are in a trailing orientation relative to the additive-manufacturing head **208**. Thus, a portion of the product **204** (e.g., Fig. 9) formed by the additive-manufacturing head **208** is positioned in the space **272** between the first and second surface-processing devices **212**. In one aspect, the portion of the product positioned in the space **272** is at least one layer L of the product **204**. In another aspect, the portion of the product positioned in the space **272** is at least two layers L of the product contemporaneously. In a further aspect, the portion of the product positioned in the space **272** is a plurality of layers L of the product, contemporaneously.

With continued reference to Figs. 3-9, the system **200** includes a guide member **268**, as indicated above. The guide member **268** may be a first guide member **268** and the system **200** may further include a second guide member **268** opposing the first guide member **268**. The first guide member **268** and the second guide member **268** are configured to engage a product formed by the additive-manufacturing head **208** to provide spacing of the first surface-processing device **212** and the second surface-processing device **212** relative to the product. The first guide member **268** is configured to engage an exterior surface **220** of the product **204** and the second guide member **268** is configured to engage an interior surface **216** of the product **204**. In the illustrated system **200**, the first guide member **268** and the second guide member **268** are guide rollers **268**. In other examples, the first and second guide members **268** may be any type of guide members such as, for example, surface tracking shoes that engage and slide against surface of the product. The first surface-processing device **212** is configured to process a first surface of a product formed by the additive-manufacturing head **208** and the second surface-processing device **212** is

configured to process a second surface of the product. The first surface is an exterior surface **220** of the product and the second surface is an interior surface **216** of the product.

The surface-processing devices **212** may be a variety of different types of processing devices **212**. In examples where the system **200** includes a single surface-processing device **212**, the surface-processing device **212** includes an aperture **276** configured to emit electromagnetic energy (see Figs. **4**, **6**, and **9**). In examples where the system **200** includes two or more surface-processing devices **212**, the aperture is a first aperture **276**, and the surface-processing device **212** further includes a second aperture **276** opposing the first aperture **276** and configured to emit electromagnetic energy (see Figs. **4**, **6**, and **9**). In one example, the first and second apertures **276** may have generally the same shape. In another example, the first aperture may have a first shape and the second aperture may have a second shape different than the first shape. In one aspect, the first aperture **276** may be the second end **264** of a first laser-delivery device **256** and the second aperture **276** may be the second end **264** of a second laser-delivery device **256**.

With continued reference to Figs. **3-11** and particular reference to Fig. **8**, an example of a block diagram of the system **200** is illustrated. The additive-manufacturing system **200** includes the additive-manufacturing head **208**, a surface-processing apparatus **280**, a power source **284**, a laser source **252**, a drive mechanism **288**, a material source **292**, a processor and/or central processing unit (CPU) **296**, memory **300**, input device **304**, and an output device **308**. The system **200** is not limited to including only the above-identified components, arranged as shown in Fig. **8** and having the features and functionality described herein. Rather, the system **200** is capable of including more, fewer, or different components and is capable of having more, fewer, or different features and functionality.

With continued reference to Fig. **8**, the power source **284** is configured to provide power to the components of the system **200**, as required. The power source **284** may be a single power source or may be comprised of a plurality of power sources working together to provide the necessary power output. Alternatively, the plurality of power sources may operate independently and may individually supply power to particular components of the system **200**. The power source **284** may be either an AC or a DC power source, or may utilize a combination of AC and DC.

The laser source **252** generates the laser beam **244** and transmits it to one or more laser outputs **312** (e.g., Fig. 5) of the additive-manufacturing head **208** for emission. The laser beam **244**, emitted from the one or more laser outputs **312**, is concentrated into a nexus or convergence. The material source **292** supplies raw material to the additive-manufacturing head **208** that will be used to manufacture the product **204**. The raw material may be any type of material having any type of form (e.g., powder, liquid, solid, etc.). The material is ejected from one or more material outputs **316** provided in the additive-manufacturing head **208**. The material outputs **316** may comprise a variety of configurations such as, for example, apertures, nozzles, etc. In the illustrated example, the additive-manufacturing head **208** includes a single material output **316**, which is comprised of an aperture **316** aligned with the nexus or convergence of the plurality of laser outputs **312**. Raw material is released from the material output **316** and enters the nexus or convergence of the laser outputs **312**, where the material is melted to form a weld pool. As the additive-manufacturing head **208** advances relative to the product being formed, the melted material forms a new layer L of the product **204**. The melted material begins to cool and harden once the material is out of the weld pool.

With additional reference to Fig. 8, the processor or CPU **296** communicates with and/or controls various components in the system **200**. The memory **300** may be a computer-readable memory medium **300** and is configured to store data required for operation of the system **200**. Computer-readable memory medium **300** is any medium which can be used to store information which can later be accessed by the processor **296**. Computer-readable memory medium **300** may include computer memory and data storage devices. Computer memory may be a fast-access memory and may be used to run program instructions executable by the processor **296**. Computer memory may include random access memory (RAM), flash memory, and read-only memory (ROM). Data storage devices may be physical devices and may be used to store any information or computer program which may be accessed by the processor **296**, such as an operating system, computer programs, program modules, and program data. Data storage devices and their associated computer-readable memory media provide storage of computer-readable instructions, data structures, program modules, and other data for the system. Data storage devices may include magnetic medium like a floppy disk, a hard disk drive, and magnetic

tape; an optical medium like a Compact Disc (CD), a Digital Video Disk (DVD), and a Blu-ray Disc; and solid state memory such as random access memory (RAM), flash memory, and read only memory (ROM).

In some aspects of the system **200**, the memory **300** includes data packets **320** 5 comprised of data required for controlled operation of the system **200**. One data packet **320** may contain data required for control of the additive-manufacturing head **208** and another data packet **320** may contain data required for control of the surface-processing apparatus **280**. The surface-processing apparatus **280** is coupled to and in a trailing orientation to the additive-manufacturing head **208**. The surface-processing apparatus **280** processes one or 10 more surfaces of the product after the material has been deposited by the additive-manufacturing head **208**. The processor **296** communicates with the memory **300** to retrieve the necessary data for controlling the orientation of the surface-processing apparatus **280** relative to the additive-manufacturing head **208**.

The subject matter of the present disclosure will be described with reference to acts 15 and symbolic representations of operations that are performed by one or more computers or computer systems, unless indicated otherwise. As such, it will be understood that such acts and operations, which are at times referred to as being computer-executed, include the manipulation by the processor **296** of the system **200** via electrical signals representing data in a structured form. This manipulation transforms the data or maintains it at specific 20 locations in the memory **300** of the system **200**, which reconfigures or otherwise alters the operation of the system **200** in a manner well understood by those skilled in the art. The data structures where data is maintained are physical locations of the memory **300** that have particular properties defined by the format of the data. However, although the subject matter of the application is being described in the foregoing context, it is not meant to be 25 limiting, as those skilled in the art will appreciate, in that some of the acts and operations described herein may also be implemented in hardware, software, and/or firmware and/or some combination thereof.

With further reference to Fig. **8**, the input device **304** allows users to input data into the system **200**. The input device **304** may have a wide variety of configurations. For 30 example, the input device **304** may be a keyboard, a keypad, a touch-screen display, an actuator, a switch, a dial, a slide mechanism, or any other type of mechanical, electrical, or

electromechanical device configured to allow a user to input information and/or control the system **200**, at least in part. Moreover, the system **200** may include a plurality of input devices **304**.

5 With continued reference to Fig. **8**, the output device **308** outputs information from the system **200** that may be perceived by a user. The output device **308** may have a wide variety of configurations. For example, the output device **308** may be display, a monitor, an alphanumeric indicator, an illumination device (e.g., a light bulb, an LED, an array of LEDs, etc.), a printer or other image-producing device, or any other type of mechanical, electrical, or electromechanical device configured to output information from the system **200** in a form
10 that is perceivable by a user. Moreover, the system **200** may include a plurality of output devices **308**.

The drive mechanism **288** is coupled to the additive-manufacturing head **208** and is controllable by the processor **296** to move the additive-manufacturing head **208** in a desired manner. Alternatively, the additive-manufacturing head **208** may remain stationary and the
15 product manufactured by the system **200** may be supported on a base or table that may be moved by the drive mechanism **288** relative to the head **208**. In either instance, the drive mechanism **288** provides the desired relative translational movement between the product **204** being formed and the additive-manufacturing system **200**. In some aspects of the system **200**, the drive mechanism **288** comprises a single drive mechanism for performing
20 all the necessary relative translational movement. In other aspects of the system **200**, the drive mechanism **288** comprises a plurality of cooperating drive mechanisms.

The surface-processing apparatus **280** is configured to process one or more surfaces of a product formed by the additive-manufacturing head **208**. The surface-processing apparatus **280** trails behind the additive-manufacturing head **208** to process the material
25 deposited by the additive-manufacturing head **208**. The surface-processing apparatus **280** may process the surfaces of the product being formed in a variety of ways. For example, in the illustrated system **200**, the surface-processing apparatus **280** may smooth or otherwise reduce the roughness of the surfaces of the product. This example of surface processing is not intended to be limiting upon the present disclosure. Rather, the system **200** is capable of
30 performing any type of surface-processing, such as, for example, coating or heat treating. The surface-processing apparatus **280** may treat a portion of the product **204** as the product

is being formed, operating in situ. In some aspects of the disclosure, the surface-processing apparatus **280** may process a single layer L of material deposited by the additive-manufacturing head **208**. In other aspects, the surface-processing apparatus **280** may process two or more layers L of material deposited by the additive-manufacturing head **208**.

5 The surface-processing apparatus **280** may also be configured to treat a plurality of layers L of the product formed by the additive-manufacturing head **208**.

Referring now to Figs. **3-11**, in the illustrated system **200**, the surface-processing apparatus **280** includes a first surface-processing device **212** and a second processing device **212**. The first and second processing devices **212** may include a wide variety of types of processing devices and, as a result, may process the surfaces of the product formed by the additive-manufacturing head **208** in a variety of ways. In the illustrated system **200**, the first and second surface-processing devices **212** are laser-emitting devices **212**. The surface-processing apparatus **280** also includes a first drive mechanism **324** configured to move the first and second surface-processing devices **212** between a first or active position, in which the first and second processing devices **212** are configured to process the surfaces of the product formed by the additive-manufacturing head **208** (see, for example, solid lines Fig. **5**), and a second or idle position, in which the first and second surface-processing devices **212** are not configured to process the surfaces of the product (as illustrated, for example, with the dashed lines in Fig. **5**). In one example, the first drive mechanism **324** is a servo-motor or a stepper-motor. In another example, the first drive mechanism may be air driven (e.g., rotary, linear, etc.), hydraulically driven (e.g., rotary, linear, etc.), or electromagnetically driven (e.g., solenoid).

In some aspects of the disclosure, the system **200** may comprise only a single surface-processing device **212** to process a single surface of the product formed by the additive-manufacturing head **208**. Thus, the second surface-processing device **212** is shown in dashed lines in Fig. **8** to illustrate an alternative aspect of the present disclosure.

Referring, for example, to Fig. **8**, the surface-processing apparatus **280** further includes the means **328** for rotatably positioning the housing **224** of the surface-processing apparatus **280** relative to the additive-manufacturing head **208**. In some aspects, the means **328** may be an open-frame servo motor coupled to the additive-manufacturing head **208**. In

other aspects, the means **328** may be other types of drive mechanisms and may have other configurations.

The surface-processing device **212** may also include a second laser source **332** configured to create a laser beam **244** to be optically communicated to the first and second surface-processing devices **212**. In this example, the second laser source **332** would provide the laser beam **244** for the surface-processing operation and the laser source **252** would provide the laser beam **244** for the additive-manufacturing head **208**.

As shown in Fig. **8**, the lines connecting the various components of the system **200** may represent a wide variety of interactions between the various components of the system **200**. Moreover, such interactions between the components may occur in either direction or may simultaneously occur in both directions. The interactions may include, but are not limited to, transfer of electrical energy or power for purposes of powering a component, communication of electrical data between components, transfer of physical matter between components, a mechanical coupling, connection, attachment, or engagement between components, or any other type of interaction that may occur in the additive-manufacturing system **200**, in one or more aspects thereof. The dashed lines connecting the various components of the system **200** may represent interactions similar in function and purpose to those represented by the solid lines, however, interactions represented by the dashed lines relate to alternative aspects of the disclosure. Likewise, components represented in dashed lines represent alternative aspects of the present disclosure.

With reference to, for example, Figs. **3** and **8**, in one example, a surface-processing apparatus **280** for an additive-manufacturing head **208** is provided. The surface-processing apparatus **280** includes a housing, **224** configured to be coupled to the additive-manufacturing head **208**, and a surface-processing device **212**, coupled to the housing **224**. The surface-processing device **212** includes one of a mechanical device or an optical device. The surface-processing device **212** is configured to move relative to the additive-manufacturing head **208**. In one aspect, the housing **224** is rotatably coupled to the additive-manufacturing head **208**. In such an aspect, the surface-processing apparatus **280** further includes means **328** for rotatably positioning the housing **224** relative to the additive-manufacturing head **208**.

As shown, for example, in Figs. 3 and 5, the surface-processing device 212 has a trailing orientation relative to the additive-manufacturing head 208. The surface-processing device 212 is configured to be spaced apart from a surface of a product 204 formed by the additive-manufacturing head 208.

5 Referring now to Figs. 3-9, in one aspect, the surface-processing device 212 is configured to emit a laser beam 244. The surface-processing apparatus 280 further includes a laser energy source 252, 332 and a laser-delivery device 256 coupled to the laser energy source 252, 332 to deliver the laser beam 244 from the laser energy source 252, 332 to a surface of a product formed by the additive-manufacturing head 208. The surface-
10 processing device 212 also includes a support member 248 coupled to the housing 224, and the laser-delivery device 256 includes a first end 260 coupled to the laser energy source 252, 332 and a second end 264 coupled to the support member 248. In one aspect, the second end 264 of the laser-delivery device 256 is generally polygonal in shape to emit the laser beam 244 having a generally polygonal cross-section. In another aspect, the second end 264
15 of the laser-delivery device 256 is generally rectangular in shape to emit the laser beam 244 having a generally rectangular cross-section. In a further aspect, the laser-delivery device 256 is configured to emit the laser beam 244 having a cross-section with a generally arcuate perimeter. In one aspect, the laser-delivery device is a fiber optic cable 256.

The surface-processing device 212 is configured to engage a product formed by the
20 additive-manufacturing head 208. In one aspect, the surface-processing device 212 is configured to optically engage a product formed by the additive-manufacturing head 208.

In one aspect, the additive-manufacturing head 208 is configured to form a product from a plurality of layers L (see Fig. 3), and the surface-processing device 212 is configured to process at least one of the plurality of layers L (see Figs. 3 and 9). In another aspect, the
25 additive-manufacturing head 208 is configured to form a product from a plurality of layers L, and the surface-processing device 212 is configured to contemporaneously process two or more of the plurality of layers L.

The surface-processing device 212 is configured to move relative to the additive-manufacturing head 208 between the first (active) position, in which the surface-processing
30 device 212 is capable of processing a product formed by the additive-manufacturing head 208 (see, for example, solid lines in Fig. 5), and the second (idle) position, in which the

surface-processing device **212** is not capable of processing the product (see, for example, dashed lines in Fig. **5**). In one aspect, the surface-processing device **212** is rotatably coupled to the housing **224** and rotates between the first position and the second position. The surface-processing apparatus **280** also includes the coupling member **246** and the support member **248**. The coupling member **246** is coupled to and between the housing **224** and the support member **248**, and the support member **248** supports the surface-processing device **212**. In one aspect, the support member **248** is configured to rotate relative to the coupling member **246**. The support member **248** is configured to rotate about the longitudinal central axis of the coupling member **246**.

In some examples, the system **200** includes multiple surface-processing devices **212**. In such aspects, the first surface-processing device **212** and the second surface-processing device **212** are spaced-apart from the first surface-processing device **212**. Both the first and second surface-processing devices **212** are in a trailing orientation relative to the additive-manufacturing head **208**. The first surface-processing device **212** is configured to process a first surface of the product formed by the additive-manufacturing head **208** and the second surface-processing device **212** is configured to process the second surface of the product. In one aspect, the first surface is an exterior surface **220** of the product **204** and the second surface is an interior surface **216** of the product **204**.

The surface-processing apparatus **280** further includes the guide member **268**. The guide member **268** is configured to engage a product formed by the additive-manufacturing head **208** and is configured to orient the surface-processing device **212** relative to the product. The guide member **268** is configured to space the surface-processing device **212** a distance away from the surface of the product. In one aspect, the guide member **268** is a guide roller. In one aspect, the surface-processing device **212** is an optical device.

The surface-processing device **212** is configured to smooth a surface of a product formed by the additive-manufacturing head **208**.

In one aspect, the surface-processing device **212** is configured to rotate about at least one axis **228**, **247**, **270**. In another aspect, the surface-processing device **212** is configured to rotate about at least two axes **228**, **247**, **270**. In a further aspect, the surface-processing device **212** is configured to rotate about three axes **228**, **247**, **270**.

In one example of the system **200**, the surface-processing device **212** includes the aperture **276** configured to emit electromagnetic energy.

The following description pertains to examples of methods and processes associated with the examples of additive-manufacturing systems described and illustrated herein.

5 While particular steps and functionality of the additive-manufacturing systems are described herein, such steps and functionality are merely examples and are not intended to be limiting. Rather, the additive-manufacturing systems are intended to include more, fewer, or different steps and functionality.

In one aspect, a method of forming a product using an additive-manufacturing head
10 **208** is provided. The method includes forming one or more layers L of the product with the additive-manufacturing head **208** and processing at least one of the one or more layers L of the product with a surface-processing device **212**, coupled to the additive-manufacturing head **208**. In one example, the step of processing the at least one of the one or more layers L of the product further includes smoothing the at least one of the one or more layers L of the
15 product. In one variant, the step of smoothing the at least one of the one or more layers L also includes smoothing the at least one of the one or more layers L along at least one of an interior surface or an exterior surface of the product. In one alternative, the step of smoothing the at least one of the one or more layers L along the at least one of the interior surface or the exterior surface further includes melting a portion of the at least one of the
20 one or more layers L. In another example, the step of smoothing the at least one of the one or more layers L also includes smoothing the at least one of the one or more layers L along both an interior surface and an exterior surface of the product. In another variant, the step of smoothing the at least one of the one or more layers L along both of the interior surface and the exterior surface also includes melting a portion of the at least one of the one or more
25 layers L.

In another alternative, the method further includes moving the surface-processing device **212** relative to the additive-manufacturing head **208**.

In a further example, the method further includes rotating the surface-processing device **212** relative to the additive-manufacturing head **208**.

30 In a further variant, the method further includes positioning the surface-processing device **212** in a trailing orientation relative to the additive-manufacturing head **208**.

In a further alternative, the method further includes spacing the surface-processing device **212** from a surface of the product.

In still another example, the surface-processing device **212** is a laser-emitting device **212**, and the step of processing the at least one of the one or more layers L further includes
5 melting a portion thereof with a laser beam **244**. In still another variant, the method also includes delivering the laser beam **244** to the at least one of the one or more layers L with a laser-delivery device **256** coupled to a laser energy source **252**.

In still another alternative, the step of processing the at least one of the one or more layers L includes contemporaneously processing two or more of the layers L.

10 In still a further example, the method further includes moving the surface-processing device **212** relative to the additive-manufacturing head **208** between a first (active) position, in which the surface-processing device **212** is capable of processing at least one of the one or more layers L of the product (see, for example, solid lines in Fig. **5**), and a second (idle) position, in which the surface-processing device **212** is not capable of processing at least one
15 of the one or more layers L of the product (see, for example, dashed lines in Fig. **5**).

In still a further variant, the surface-processing device **212** includes a first surface-processing device **212** and a second surface-processing device **212**, and the step of processing further includes processing the at least one of the one or more layers L with the first surface-processing device **212** and the second surface-processing device **212**. In still a
20 further alternative, the first processing device **212** and the second processing device **212** are spaced-apart from one another and in a trailing orientation relative to the additive-manufacturing head **208**. In another example, the step of processing the at least one of the one or more layers L further includes processing a first surface of the product with the first surface-processing device **212** and processing a second surface of the product with the
25 second surface-processing device **212**. In another variant, the first surface is an exterior surface of the product and the second surface is an interior surface of the product.

In another alternative, the method further includes spacing the surface-processing device **212** away from the product. In a further example, the step of spacing the surface-processing device **212** away from the product is achieved using a guide member **268**
30 engaging a surface of the product.

In a further variant, a vehicle, such as an aircraft, a marine vessel, a land vehicle, etc., includes a product manufactured by a method of forming a product using the additive-manufacturing head **208**. In a further alternative, the method includes forming one or more layers L of the product with the additive-manufacturing head **208**, and processing at least one of the one or more layers L of the product with the surface-processing device **212** coupled to the additive-manufacturing head **208**.

Referring now to Figs. **12-15**, another example of the system **200** is illustrated. The system **200** illustrated in Figs. **12-15** includes some similar structure and functionality to the system **200** illustrated in Figs. **3-11**. The following description relates to at least some of the differences between the two illustrative systems.

With reference to Figs. **12-15**, one aspect of the additive-manufacturing system **200** includes the additive-manufacturing head **208** (Figs. **3**, **5** and **12**) and the surface-processing device **212**, e.g., an abrasive cutter **212** (Fig. **12**), coupled to the additive-manufacturing head **208**. In one example, the surface-processing device **212** is configured to engage a product **204** (Fig. **15**), formed by the additive-manufacturing head **208**. In one variant, as illustrated in Fig. **13**, the system **200** further includes a first drive mechanism **324**, means **328** for rotatably positioning the housing **224** relative to the additive manufacturing head **208**, and a second drive mechanism **400**, operatively coupled to the abrasive cutter **212** to rotate the abrasive cutter **212**. In one alternative, the system **200** also includes a housing **224** and a support member **248** coupled to the housing **224**. In a further example, the housing **224** is coupled to the additive-manufacturing head **208**, and the second drive mechanism **400** and the abrasive cutter **212** are supported by the support member **248**.

As stated above, in one variant, the surface-processing device **212** is the abrasive cutter **212**. In the illustrated system **200**, the surface-processing device includes the first abrasive cutter **212** and the second abrasive cutter **212**, spaced-apart from one another. The first abrasive cutter **212** and the second abrasive cutter **212** respectively include the second drive mechanism **400** and the third drive mechanism **400**, each configured to rotate one of the first and second abrasive cutters **212**. The abrasive cutters may rotate in the same or opposite directions. Alternatively, a single drive mechanism, e.g., the second drive mechanism **400**, may be used to rotate both abrasive cutters. The abrasive cutters **212** are supported by a support member **248**, which is rotatably coupled to a coupling member **246**.

The support member **248** and the abrasive cutters **212** rotate about a coupling-member axis **247**, extending longitudinally through a center of the coupling member **246**. The coupling member **246** is rotatably coupled to the housing **224**, e.g., by a shaft **269**. An axis **270** extends longitudinally through a center of the shaft **269** and the coupling member **246**,
5 support members **248**, and abrasive cutters **212** rotate about the axis **270**. The abrasive cutters **212** are configured to engage and process a first surface and a second surface of a product formed by the additive-manufacturing head **208**. The first surface may be an interior surface of the product and the second surface may be an exterior surface of the product, or vice versa.

10 With particular reference to Fig. **13**, the system **200** may include similar features and components to the system **200** illustrated in Figs. **3-11**. For example, the system **200** illustrated in Fig. **13** includes a similar additive-manufacturing head **208**, laser source **252**, drive mechanism **288**, material source **292**, power source **284**, processor or CPU **296**, memory **300**, input device **304** and output device **308**. At least some of the differences
15 between the system **200** illustrated in Fig. **8** and the system **200** illustrated in Fig. **13** include, in one example, a second drive mechanism **400**, configured to rotate both the first and second surface-processing devices **212** to process surfaces of a product formed by the additive-manufacturing head **208**. In one variant, the first and second surface-processing devices **212** are first and second abrasive cutters **212** and the second drive mechanism **400**
20 rotates the abrasive cutters **212** to abrade or cut the surfaces of the product. In one alternative, the second drive mechanism **400** is a servo-motor or a stepper-motor. In another example, the second drive mechanism **400** may be an air motor, a hydraulic motor, or an electric motor (e.g., AC or DC). In another variant, the system **200** may only include a single surface-processing device **212** to process a single surface of a product. Thus, the
25 second surface-processing device **212** is shown in dashed lines in Fig. **13** to demonstrate that it may be optional.

In another alternative, the system **200** may also include a third drive mechanism **400** configured to rotate the second surface-processing device **212** to process a surface of the product. In this alternative, the second drive mechanism **400** rotates the first surface-
30 processing device **212** to process a first surface of the product and the third drive mechanism **400** rotates the second surface-processing device **212** to process a second surface of the

product. In a further example, the third drive mechanism **400** is a servo-motor or a stepper-motor. In a further variant, the third drive mechanism **400** may be an air motor, a hydraulic motor, or an electric motor (e.g., AC or DC).

In still another example, the system **200** also includes the first drive mechanism **324**
5 that is configured to rotate the first and second surface-processing devices **212** between a first or processing position, in which the first and second surface-processing devices **212** are configured to process surfaces of a product, and a second or idle position, in which the first and second surface-processing devices **212** are not configured to process surfaces of the product. In still another variant, the system **200** may only include a single surface-
10 processing device **212** to process a single surface of a product.

In still another alternative, the system **200** may further include means **328** for rotatably positioning the housing **224** relative to the additive manufacturing head **208**. The means **328** ensures that the surface-processing apparatus **280** properly trails behind the additive-manufacturing head **208** to process the desired portion of the product. In still a
15 further example, the means **328** may be an open-frame servo motor coupled to the additive-manufacturing head **208**.

The lines connecting the various components of the system **200** may represent a wide variety of interactions between the various components of the system **200**. Moreover, such interactions between the components may travel in either direction or may allow
20 interactions to travel in both directions. The interactions may include, but are not limited to, conveyance of electrical energy or power for purposes of powering a component, communication of electrical data between components, conveyance of physical matter between components, a mechanical coupling, connection, attachment, or engagement between components, or any other type of interaction that may occur in the additive-
25 manufacturing system **200**, in one or more aspects thereof. The dashed lines connecting the various components of the system **200** may be similar in function and purpose as the solid lines, however, the dashed lines represent that the interaction may be optional.

With reference to Fig. **14**, for example, the abrasive cutters **212** are configured to be oriented at different angles. In one example, the abrasive cutters **212** are oriented in a
30 vertical manner (see solid lines), such that abrading surfaces **416** of the abrasive cutters **212** are generally vertical and parallel to a vertical axis **420**. In one variant, the abrasive cutters

212 are oriented obliquely (see phantom and dashed lines – two different orientations) such that abrading surfaces **416** of the abrasive cutters **212** are generally transverse to the vertical axis **420**.

5 Referring now to Fig. **15**, the abrasive cutters **212** may, for example, have different dimensions to process or abrade various portions of a product formed by the additive-manufacturing head **208**. In one example, the abrasive cutters **212** may be sized to process or abrade a single layer L of the product (see solid lines). In one variant, the abrasive cutters **212** may be sized to simultaneously process or abrade two or more layers L of the product (see dashed lines).

10 Referring again to Figs. **12-15**, in one example, the surface-processing device **212** is configured to physically engage a product formed by the additive-manufacturing head **208**. In such an example, the surface-processing device may be the abrasive cutter **212**, and the surface-processing apparatus **280** may further include the drive mechanism **400** coupled to the abrasive cutter **212** for rotating the abrasive cutter **212**. In one variant, the surface-
15 processing apparatus **280** further includes the housing **224** and the support member **248**, coupled to the housing **224**. In one alternative, the housing **224** may be configured to couple to the additive-manufacturing head **208**, and the drive mechanism **400** and the abrasive cutter **212** may be supported by the support member **248**.

The following description pertains to examples of methods and processes associated
20 with the examples of additive-manufacturing systems described and illustrated in Figs. **12-15**. While particular steps and functionality of the additive-manufacturing systems are described herein, such steps and functionality are merely examples and are not intended to be limiting. Rather, the additive-manufacturing systems are intended to include more, fewer, and different steps and functionality.

25 In one aspect, a method of forming a product using the additive-manufacturing head **208** is provided. The method includes forming one or more layers L of the product **204** with the additive-manufacturing head **208** and processing at least one of the one or more layers L of the product with the surface-processing device **212**, coupled to the additive-manufacturing head **208**. In one example, the step of processing the at least one of the one
30 or more layers L of the product also includes smoothing the at least one of the one or more layers L of the product. In one variant, the step of smoothing the at least one of the one or

more layers L further includes smoothing the at least one of the one or more layers L along at least one of an interior surface or an exterior surface of the product. In one alternative, the step of smoothing the at least one of the one or more layers L along the at least one of the interior surface or the exterior surface also includes abrading a portion of the at least one
5 of the one or more layers L. In another example, the step of smoothing the at least one of the one or more layers L along both the interior surface and the exterior surface also includes abrading a portion of the at least one of the one or more layers L.

In another variant, the step of processing the at least one of the one or more layers L of the product further includes engaging the surface-processing device **212** with the at least
10 one of the one or more layers L of the product. In another alternative, the surface-processing device **212** is the abrasive cutter **212**, and the step of engaging the at least one of the one or more layers L of the product further includes abrading a portion of the at least one of the one or more layers L of the product with the abrasive cutter **212** configured to be rotated by the drive mechanism **400**. In a further example, the method further includes
15 supporting the drive mechanism **400** and the abrasive cutter **212** with the support member **248**. The support member **248** is coupled to the housing **224** and the housing **224** is configured to be coupled to the additive-manufacturing head **208**.

Referring now to Fig. **16**, an aspect of the additive manufacturing system **200** is illustrated. In one example, the additive-manufacturing system **200** includes the additive-
20 manufacturing head **208** and the surface-processing device **212**, coupled to the additive-manufacturing head **208**.

With reference to Fig. **17**, an aspect of the surface processing apparatus **280** is illustrated. In one variant, the surface-processing apparatus includes the housing **224** configured to be coupled to the additive-manufacturing head **208** and also includes the
25 surface-processing device **212**, coupled to the housing **224**.

As realized herein, a variety of different aspects, examples, variants and alternatives of additive-manufacturing systems, apparatuses and methods are disclosed herein that include a variety of components, features, and functionality. It should be understood that the various aspects, examples, variants and alternatives of systems, apparatuses and methods
30 disclosed herein are capable of including any of the components, features, and functionality

of any of the other aspects, examples, variants and alternatives of systems, apparatuses, and methods disclosed herein in any combination.

It should be understood that the terms aspect, example, variant and alternative may be used interchangeably herein and the various uses of such terms is not intended to limit
5 the present disclosure in any manner.

The Abstract of the disclosure is provided to allow the reader to quickly ascertain the nature of the technical disclosure. It is submitted with the understanding that it will not be used to interpret or limit the scope or meaning of the claims. In addition, in the foregoing Detailed Description, it can be seen that various features are grouped together in various
10 embodiments for the purpose of streamlining the disclosure. This method of disclosure is not to be interpreted as reflecting an intention that the claimed embodiments require more features than are expressly recited in each claim. Rather, as the following claims reflect, inventive subject matter lies in less than all features of a single disclosed embodiment. Thus, the following claims are hereby incorporated into the Detailed Description, with each
15 claim standing on its own as a separately claimed subject matter.

While various embodiments of the disclosure have been described, it will be apparent to those of ordinary skill in the art that other embodiments and implementations are possible within the scope of the disclosure. Accordingly, the disclosure is not to be restricted except in light of the attached claims and their equivalents.

EMBODIMENTS IN WHICH AN EXCLUSIVE PROPERTY OR PRIVILEGE IS CLAIMED ARE DEFINED AS FOLLOWS:

1. An additive-manufacturing system, comprising:
 - an additive-manufacturing head, operable to deposit a new layer of material on an existing layer of material and melt the new layer of material to weld the new layer of material to the existing layer of material; and
 - a surface-processing device, coupled to the additive-manufacturing head, and wherein the surface-processing device comprises a laser-emitting device configured to emit a first laser beam and a second laser beam that smooth, respectively, a first surface and a second surface of at least one of the new layer of material and the existing layer of material.
2. The additive-manufacturing system of claim 1, wherein the surface-processing device is movably coupled to the additive-manufacturing head.
3. The additive-manufacturing system of claim 2, further comprising a housing, rotatably coupled to the additive-manufacturing head, and wherein the surface-processing device is coupled to the housing.
4. The additive-manufacturing system of claim 3, further comprising means for rotatably positioning the housing relative to the additive-manufacturing head.
5. The additive-manufacturing system of claim 1, wherein the surface-processing device has a trailing orientation relative to the additive-manufacturing head.
6. The additive-manufacturing system of claim 1, further comprising a support member, a laser energy source, and a laser-delivery device that comprises a first end, optically coupled to the laser energy source, and a second end, coupled to the support member.

7. The additive-manufacturing system of claim 1, wherein the laser-emitting device is configured to be spaced-apart from a surface of a product, formed by the additive-manufacturing head.
8. The additive-manufacturing system of claim 1, wherein the laser-emitting device comprises:
 - a first laser-emitting device, configured to emit the first laser beam, and wherein the first laser beam is configured to smooth the first surface of the at least one of the new layer of material and the existing layer of material; and
 - a second laser-emitting device, configured to emit the second laser beam, and wherein the second laser beam is configured to smooth the second surface of the at least one of the new layer of material and the existing layer of material.
9. The additive-manufacturing system of claim 1 or 8, wherein:
 - the first surface is on a first side of the at least one of the new layer of material and the existing layer of material;
 - the second surface is on a second side of the at least one of the new layer of material and the existing layer of material; and
 - the first side and the second side are opposite each other.
10. The additive-manufacturing system of claim 1, further comprising a guide member, configured to engage a product, formed by the additive-manufacturing head to orient the surface-processing device relative to the product.
11. The additive-manufacturing system of claim 10, wherein the guide member spaces the surface-processing device relative to the product.

12. The additive-manufacturing system of claim 6, wherein:
- the laser-emitting device comprises the second end of the laser-delivery device,
and
- the second end is configured to be generally polygonal in shape to emit at least one of the first laser beam, having a generally polygonal cross-section, and the second laser beam, having a generally polygonal cross-section.
13. The additive-manufacturing system of claim 1, further comprising a laser energy source and a laser-delivery device, and wherein the laser-delivery device is optically coupled to the laser energy source and to the laser-emitting device.
14. The additive-manufacturing system of claim 13, further comprising a housing and a support member, and wherein:
- the support member is coupled to the housing; and
- the housing is coupled to the additive-manufacturing head.
15. The additive-manufacturing system of any one of claims 1 to 11, 13 and 14, wherein the laser-emitting device is polygonal in shape to emit at least one of the first laser beam, having a generally polygonal cross-section, and the second laser beam, having a generally polygonal cross-section.
16. The additive-manufacturing system of any one of claims 1 to 11 and 13 to 15, wherein the laser-emitting device is rectangular in shape to emit at least one of the first laser beam, having a generally rectangular cross-section, and the second laser beam, having a generally rectangular cross-section.
17. The additive-manufacturing system of any one of claims 1 to 11, 13 and 14, wherein the laser-emitting device is configured to emit at least one of the first laser beam,

having a generally arcuate perimeter shape, and the second laser beam, having a generally arcuate perimeter shape.

18. The additive-manufacturing system of any one of claims 1 to 11, 13, 14 and 17, wherein the laser-emitting device is configured to emit at least one of the first laser beam, having a generally circular shape, and the second laser beam, having a generally circular shape.
19. The additive-manufacturing system of claim 6 or 13, wherein the laser-delivery device comprises a fiber optic cable.
20. A method of forming a product using an additive-manufacturing head, the method comprising steps of:
 - causing the additive-manufacturing head to form one or more layers of the product; and
 - causing a first laser beam and a second laser beam to smooth, respectively, a first surface and a second surface of at least one of the one or more layers.
21. The method of claim 20, wherein the step of causing the first laser beam and the second laser beam to smooth, respectively, the first surface and the second surface of the at least one of the one or more layers comprises causing the first laser beam and the second laser beam to smooth at least one of the one or more layers along, respectively, an interior surface and an exterior surface of the product.
22. The method of claim 21, wherein the step of causing the first laser beam and the second laser beam to smooth the at least one of the one or more layers along, respectively, the interior surface and the exterior surface of the product comprises causing at least one of the first laser beam and the second laser beam to melt a portion of the at least one of the one or more layers.

23. The method of any one of claims **20** to **22**, further comprising causing at least one of a source of the first laser beam and a source of the second laser beam to move relative to the additive-manufacturing head.
24. The method of claim **20**, further comprising causing at least one of the first laser beam and the second laser beam to abrade the one or more layers of the product.
25. The method of claim **24**, further comprising causing at least one of a source of the first laser beam and a source of the second laser beam to move relative to the additive-manufacturing head.
26. The method of claim **20**, further comprising causing at least one of a source of the first laser beam and a source of the second laser beam to rotate relative to the additive-manufacturing head.
27. The method of claim **20**, further comprising positioning at least one of a source of the first laser beam and a source of the second laser beam in a trailing orientation relative to the additive-manufacturing head.
28. An additive-manufacturing system, comprising:
 - (a) an additive-manufacturing head;
 - (b) a surface-processing device, coupled to the additive-manufacturing head;
 - (c) a support member, coupled to the additive-manufacturing head;
 - (d) a laser energy source; and
 - (e) a laser-delivery device, comprising a first end, optically coupled to the laser energy source, and a second end, coupled to the support member, andwherein the surface-processing device comprises a laser-emitting device, configured to emit a first and a second laser beam, arranged to smooth at least

one of one or more layers of material produced by the additive-manufacturing system, along, respectively, an interior surface and an exterior surface of the one or more layers of material by melting a portion of the at least one of the one or more layers.

29. The additive-manufacturing system of claim 28, wherein the surface-processing device is movably coupled to the additive-manufacturing head.
30. The additive-manufacturing system of claim 29, further comprising a housing, rotatably coupled to the additive-manufacturing head, and wherein the surface-processing device is coupled to the housing.
31. The additive-manufacturing system of claim 30, wherein the support member is coupled to the additive-manufacturing head by being coupled to the housing.
32. The additive-manufacturing system of claim 30 or 31, further comprising means for rotatably positioning the housing relative to the additive-manufacturing head.
33. The additive-manufacturing system of any one of claims 28 to 32, wherein the surface-processing device has a trailing orientation relative to the additive-manufacturing head.
34. The additive-manufacturing system of any one of claims 28 to 33, wherein the surface-processing device is configured to engage a product, formed by the additive-manufacturing head.
35. A method of forming a product using an additive-manufacturing system in accordance with any one of claims 28 to 33, the method comprising:

forming one or more layers of the product with the additive-manufacturing head;
and

processing at least one of the one or more layers of the product with the surface-processing device, comprising the laser-emitting device configured to emit the first laser beam and the second laser beam, by smoothing the at least one of the one or more layers of the product along the interior surface and the exterior surface of the at least one of the one or more layers of the product by melting a portion of the at least one of the one or more layers of the product with the first laser beam and the second laser beam.

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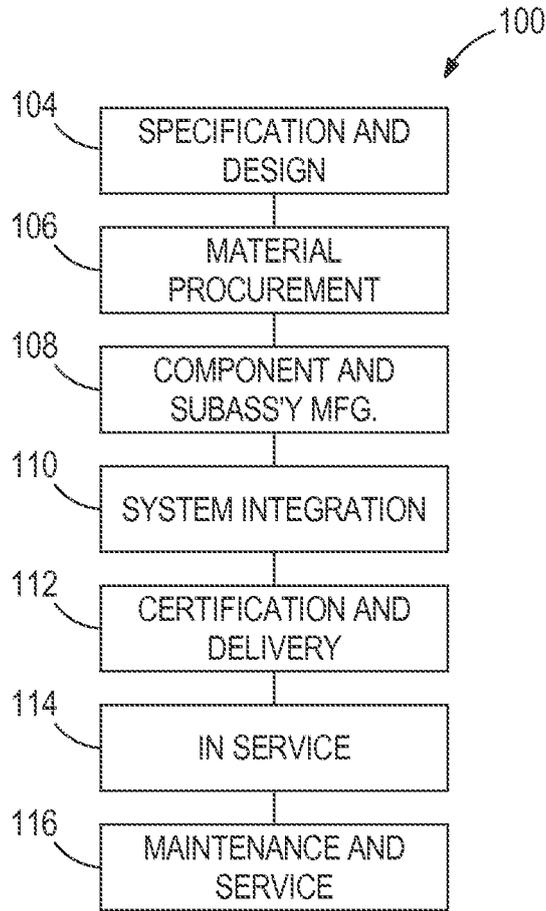


FIG. 1

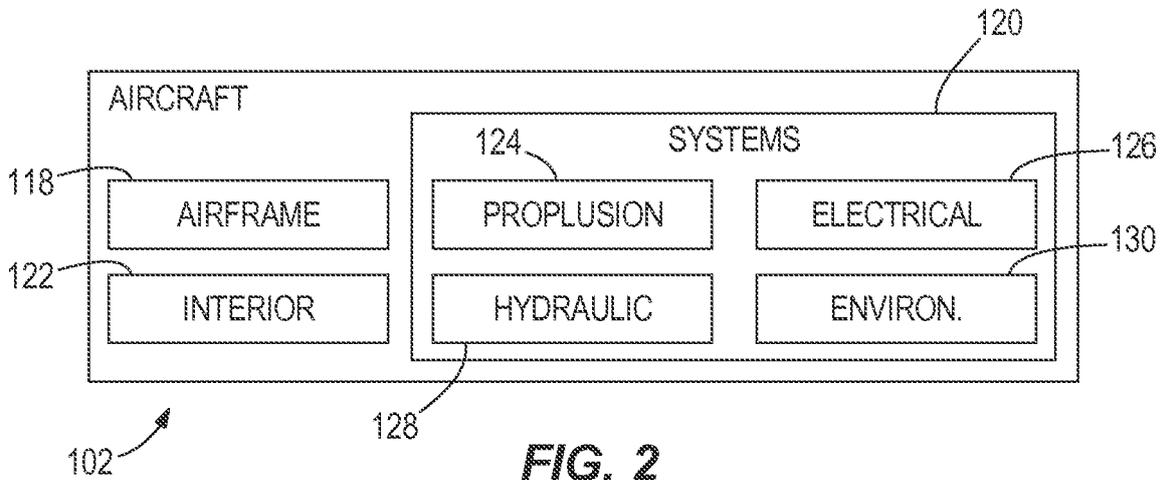


FIG. 2

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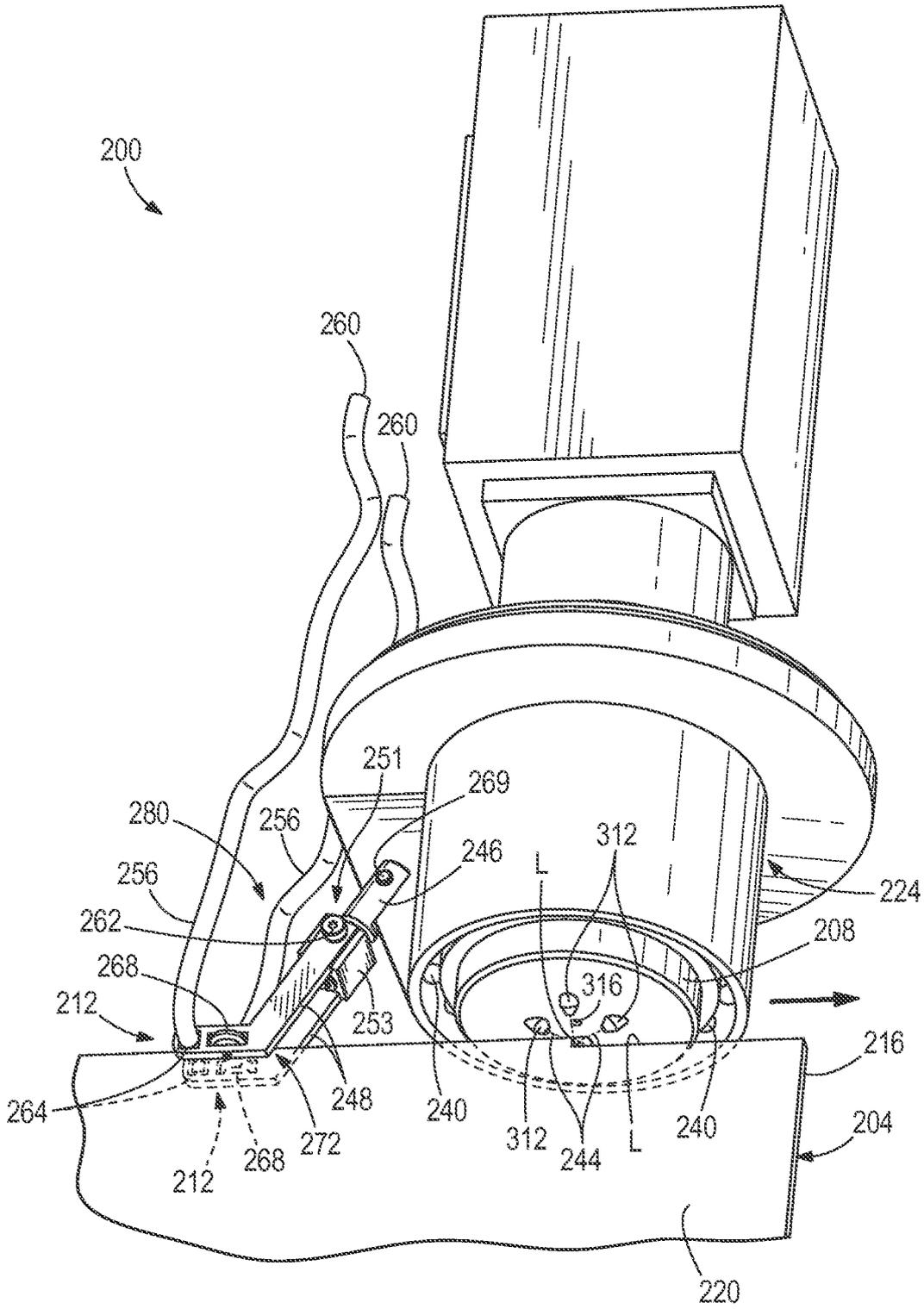


FIG. 3

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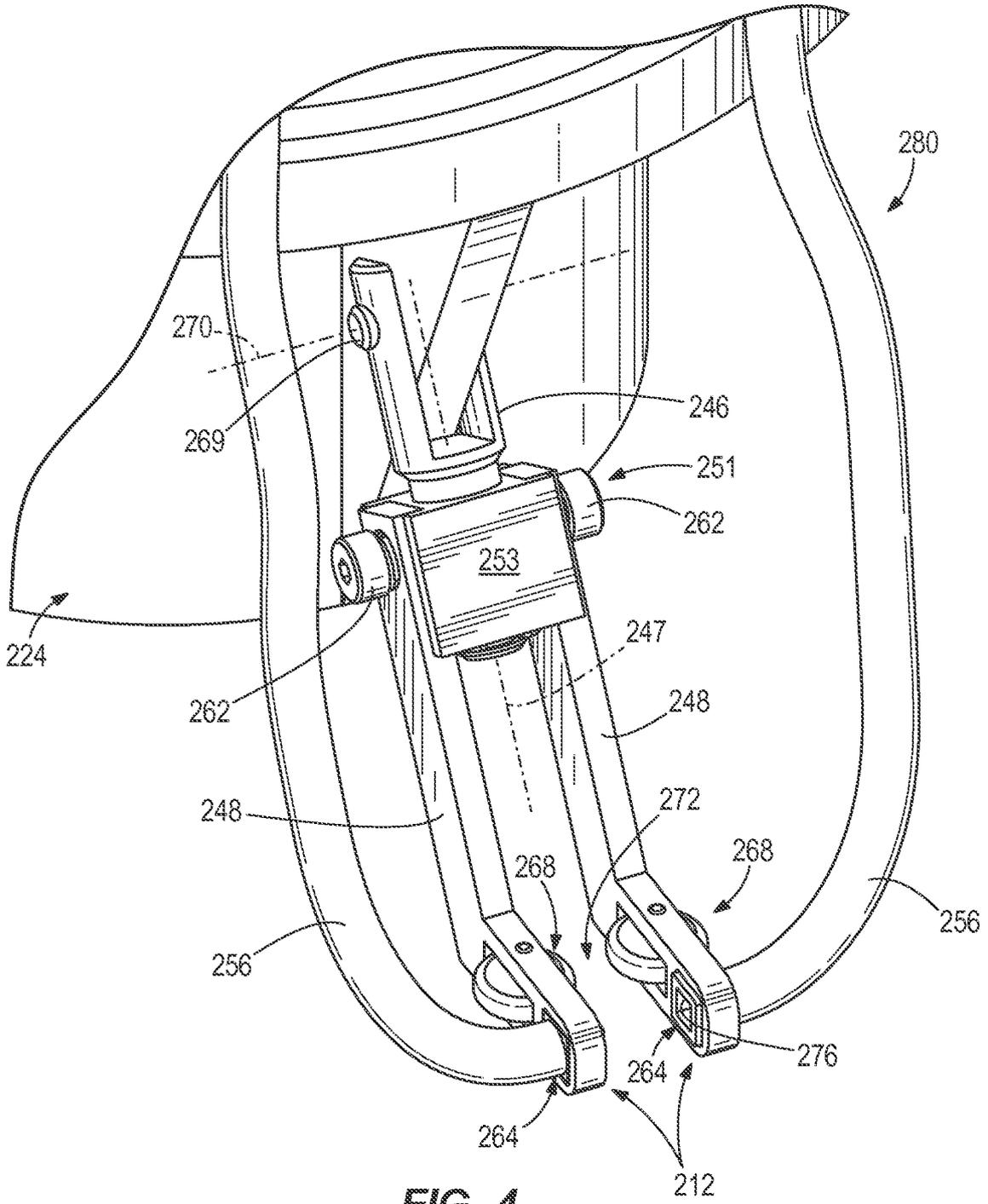


FIG. 4

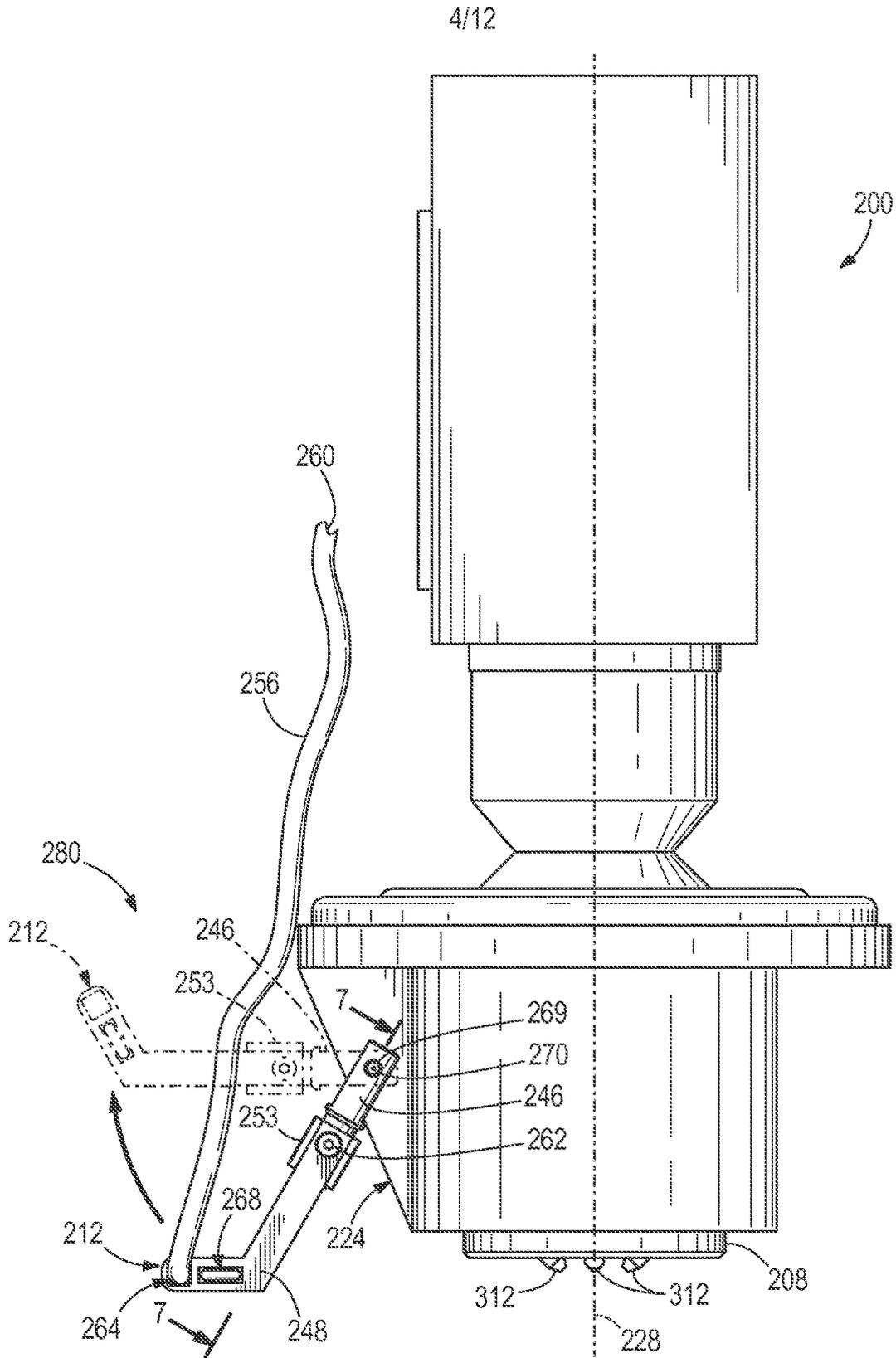


FIG. 5

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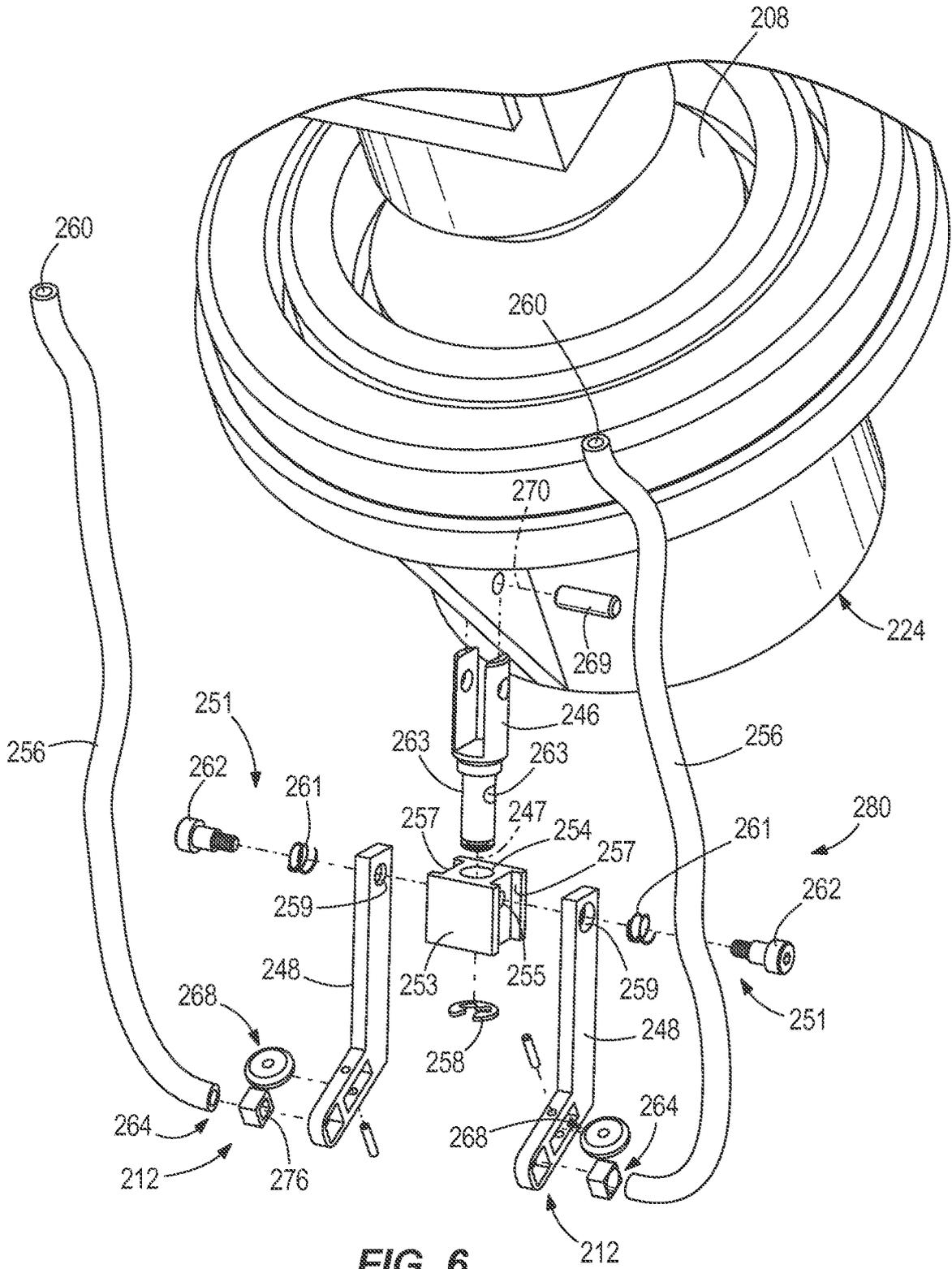


FIG. 6

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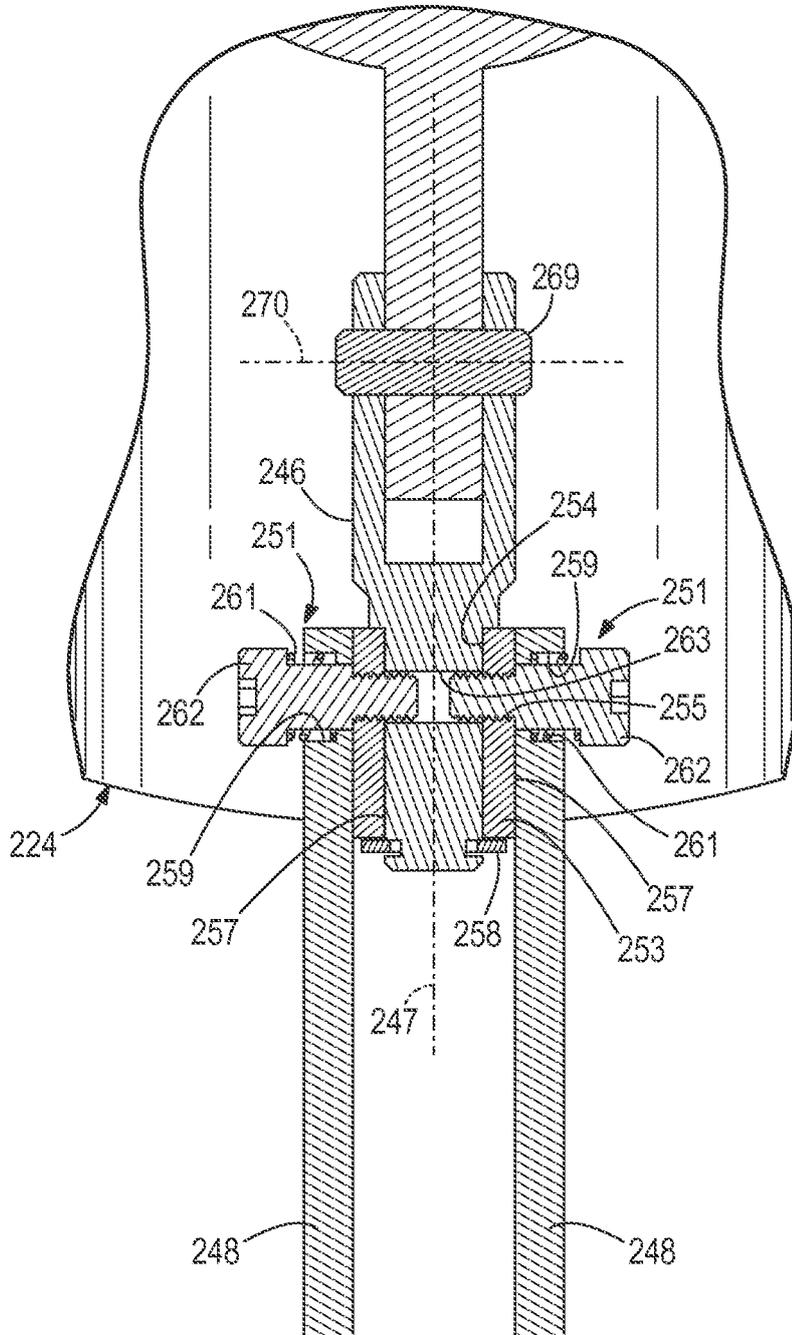


FIG. 7

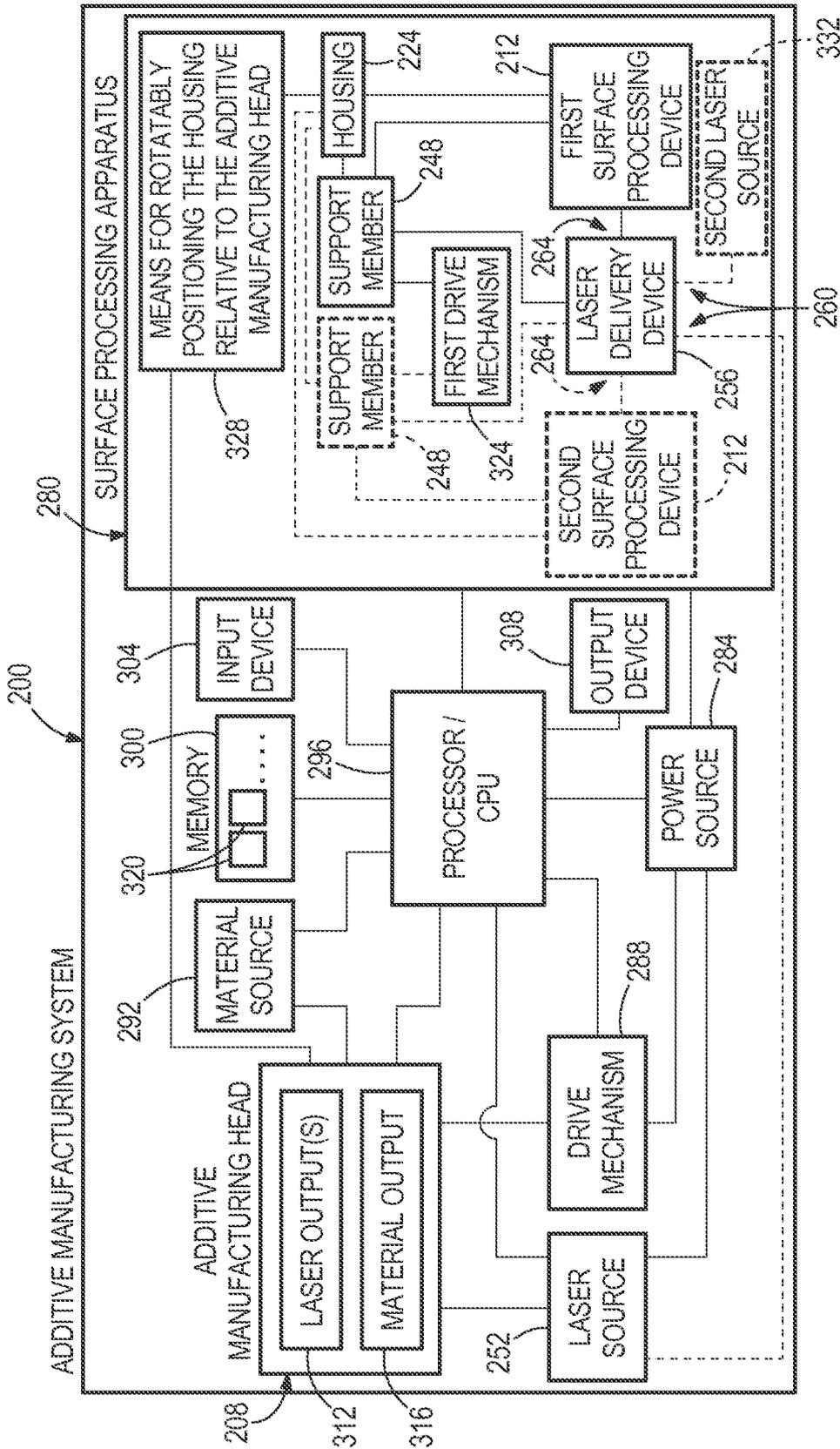


FIG. 8

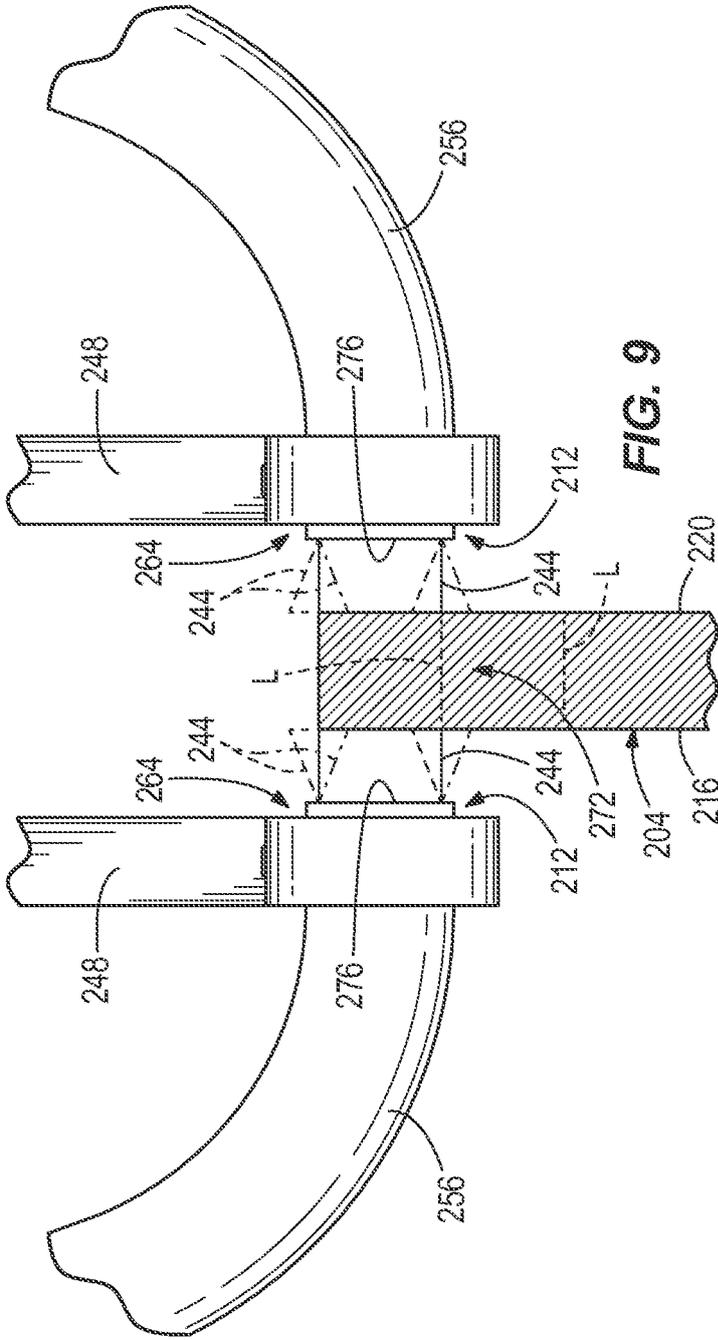


FIG. 9

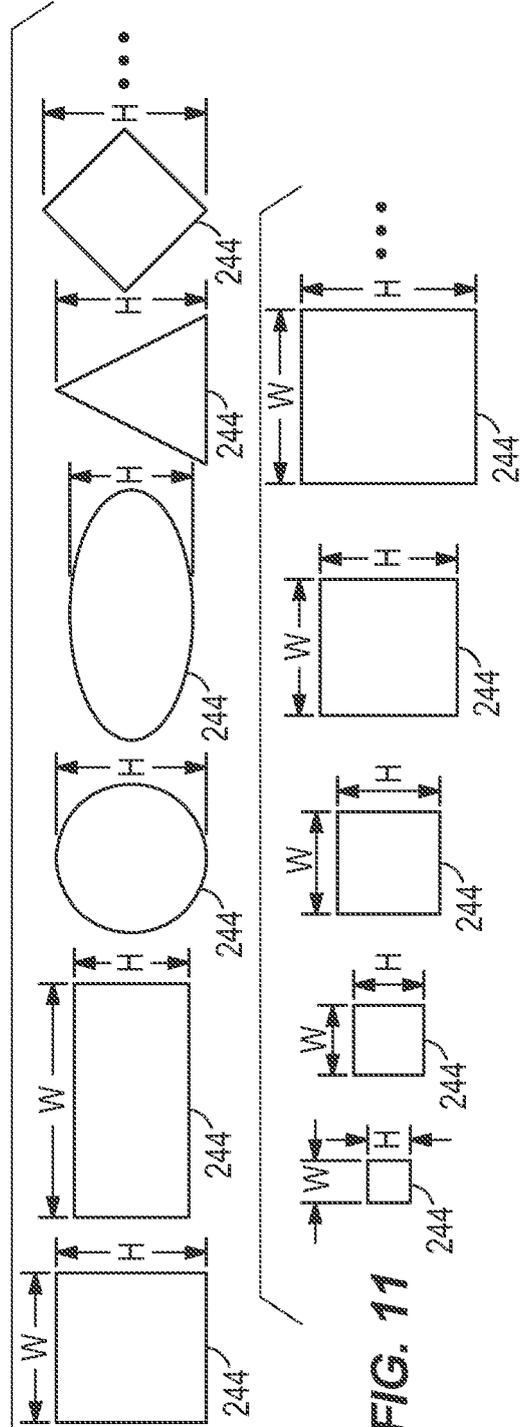


FIG. 10

FIG. 11

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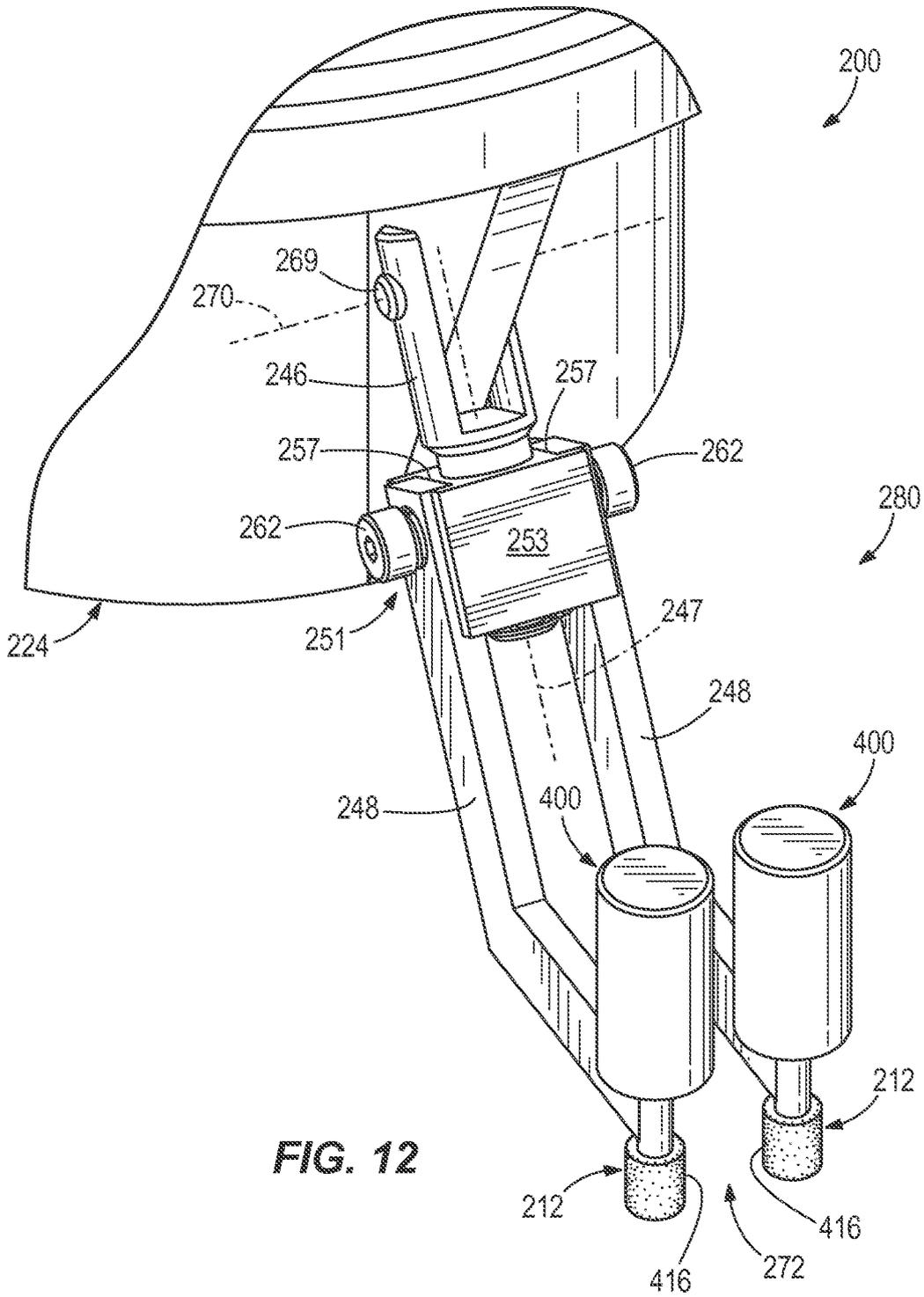


FIG. 12

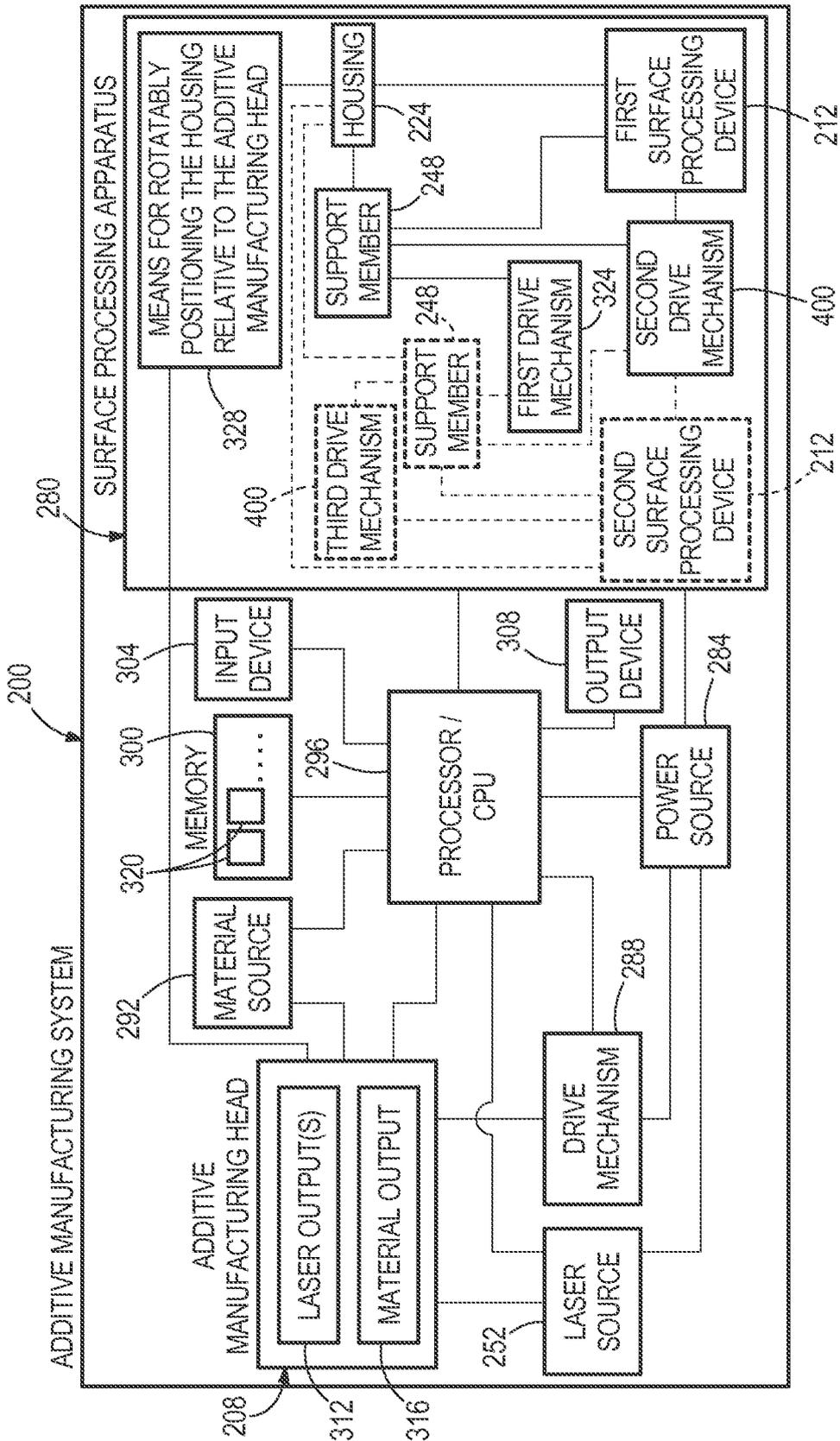


FIG. 13

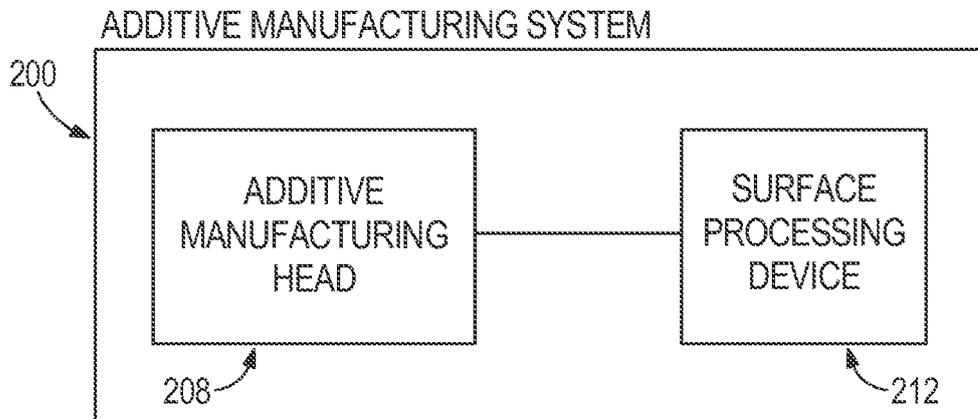


FIG. 16

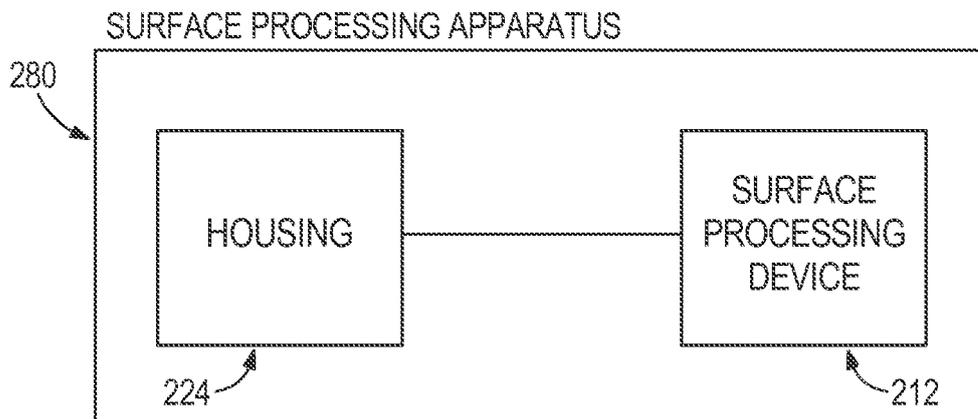


FIG. 17

