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Comb

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(54) **MAGNETIC PLATEN ASSEMBLY FOR ADDITIVE MANUFACTURING SYSTEM**

(71) Applicant: **Stratasys, Inc.**, Eden Prairie, MN (US)

(72) Inventor: **James W. Comb**, Hamel, MN (US)

(73) Assignee: **Stratasys, Inc.**, Eden Prairie, MN (US)

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G03G 15/22	(2006.01)

(52) **U.S. Cl.**

CPC ***B29C 67/0092*** (2013.01); ***B29C 67/0085*** (2013.01); ***G03G 15/224*** (2013.01); *B29C 67/0055* (2013.01); *B29C 67/0081* (2013.01); *G03G 15/225* (2013.01)

(58) **Field of Classification Search**

CPC B29C 67/0092; B29C 67/0085; B29C 67/0081; B29C 67/0055

See application file for complete search history.

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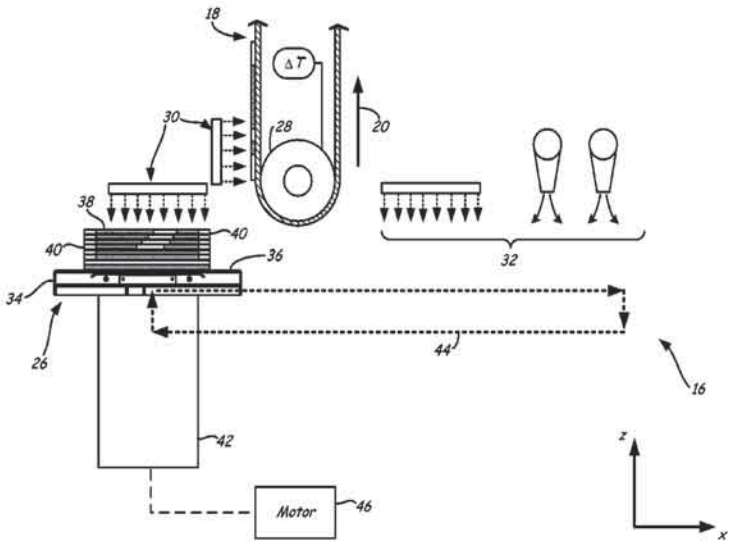
Primary Examiner — Galen Hauth

(74) *Attorney, Agent, or Firm* — Peter J. Ims; Westman, Champlin & Koehler, P.A.

(57) **ABSTRACT**

A platen assembly for use in an additive manufacturing system, which includes a platen plate that is preferably secured to a gantry mechanism of the additive manufacturing system, and having a top surface, and one or more magnets secured to the platen plate and configured to generate one or more magnetic fields at the top surface of the platen plate. The platen gantry is configured to magnetically couple interchangeable and replaceable build sheets to the top surface of the platen plate due to the one or more generated magnetic fields, and where the magnetically-coupled build sheets are configured to receive the printed layers from the printing mechanism.

14 Claims, 7 Drawing Sheets



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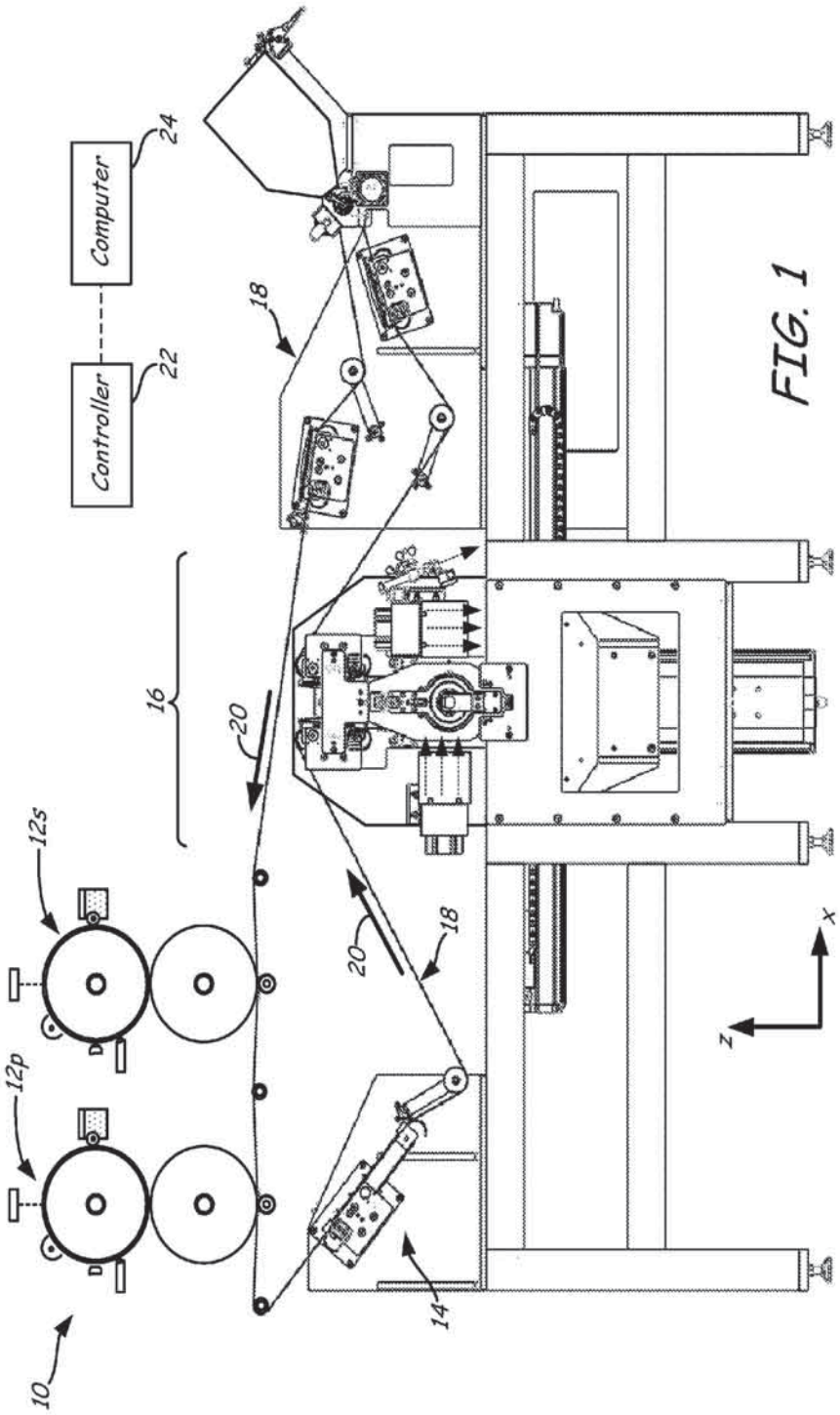


FIG. 1

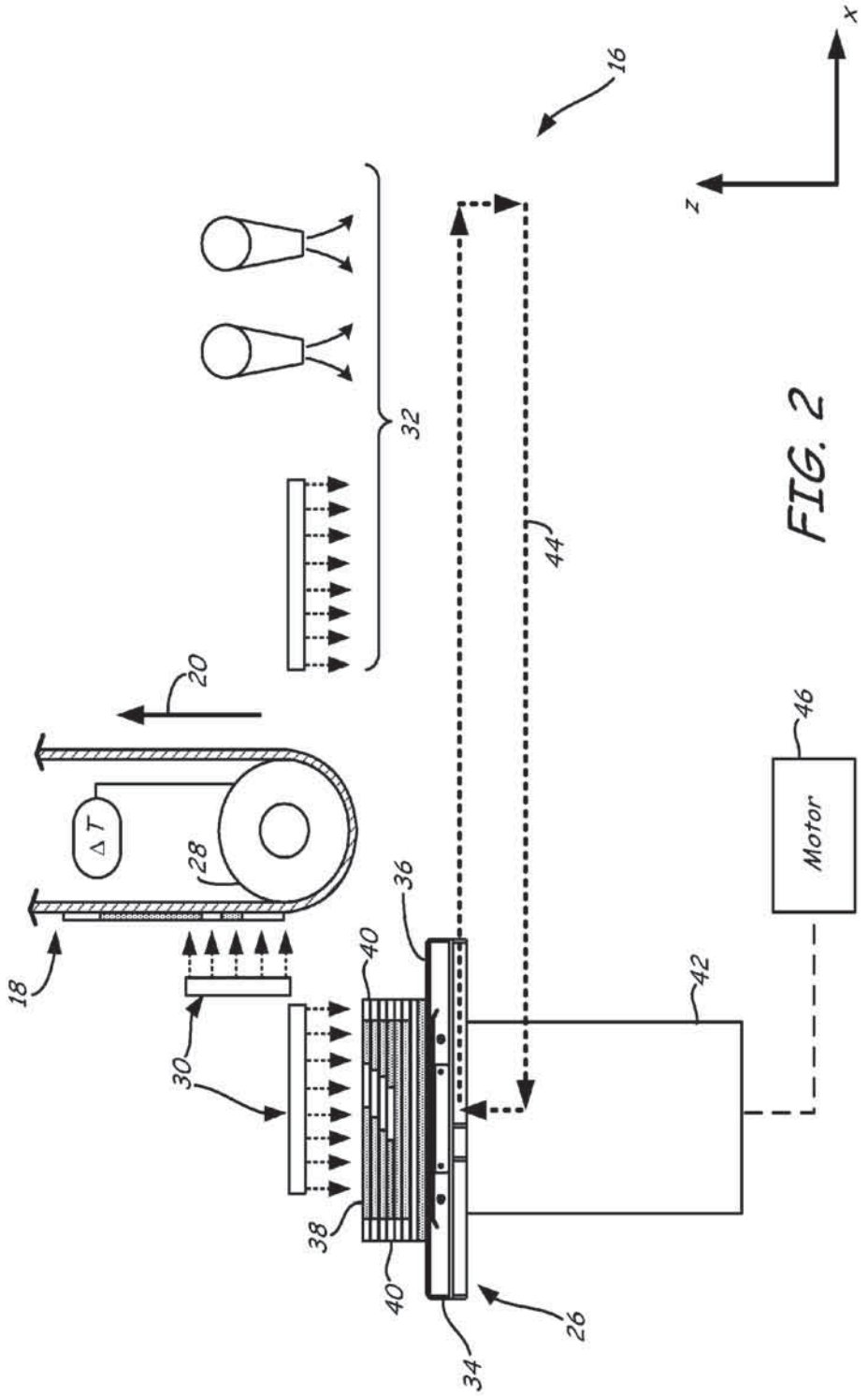
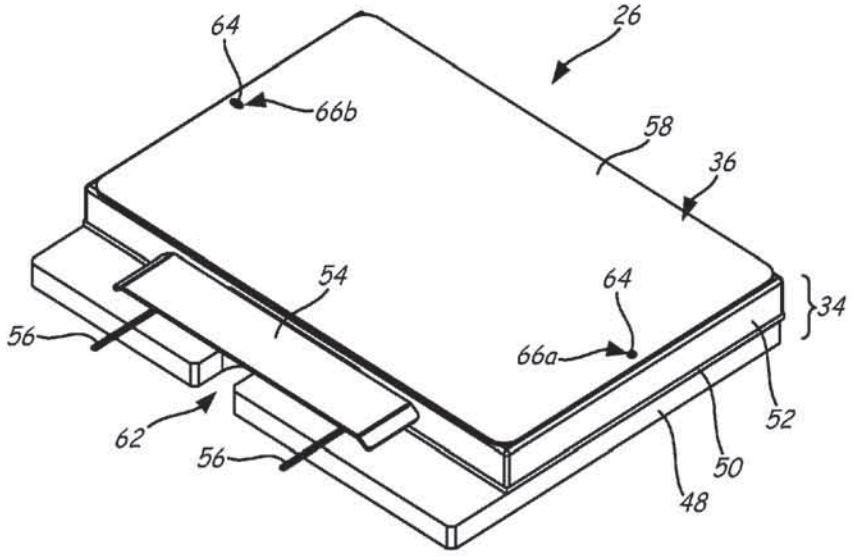


FIG. 2

FIG. 3


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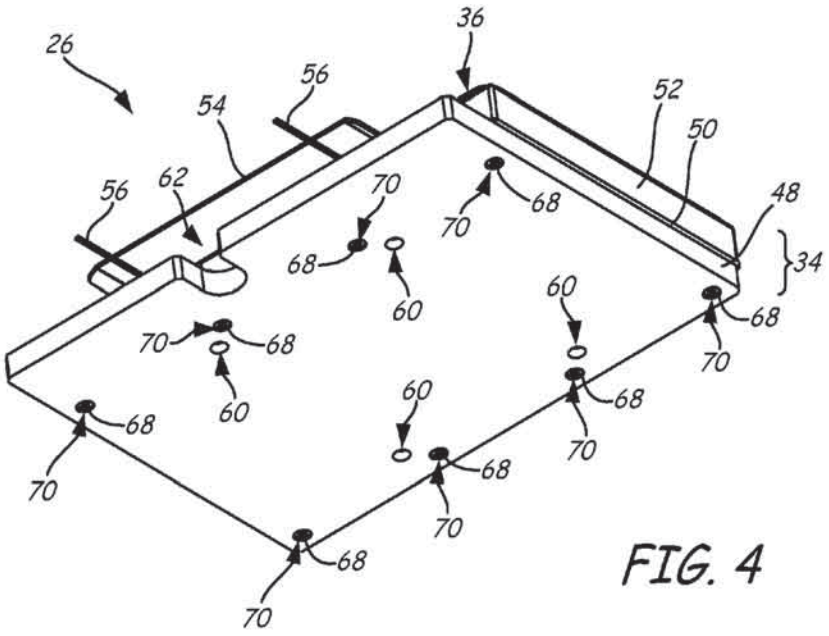

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FIG. 4

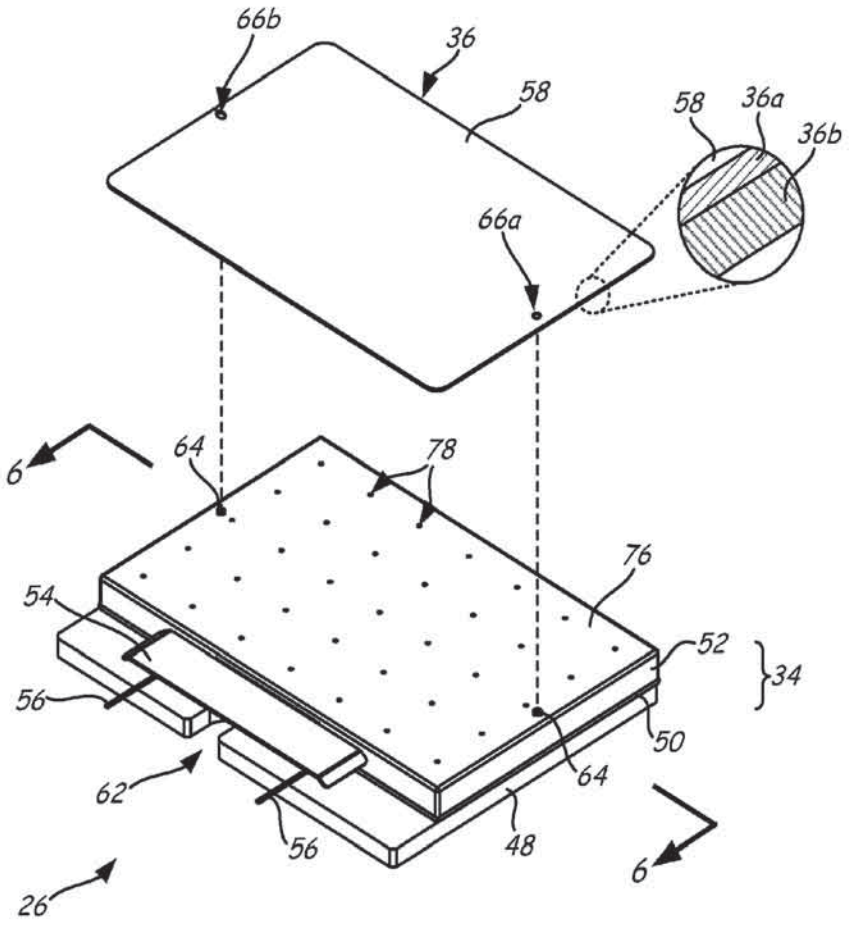


FIG. 5

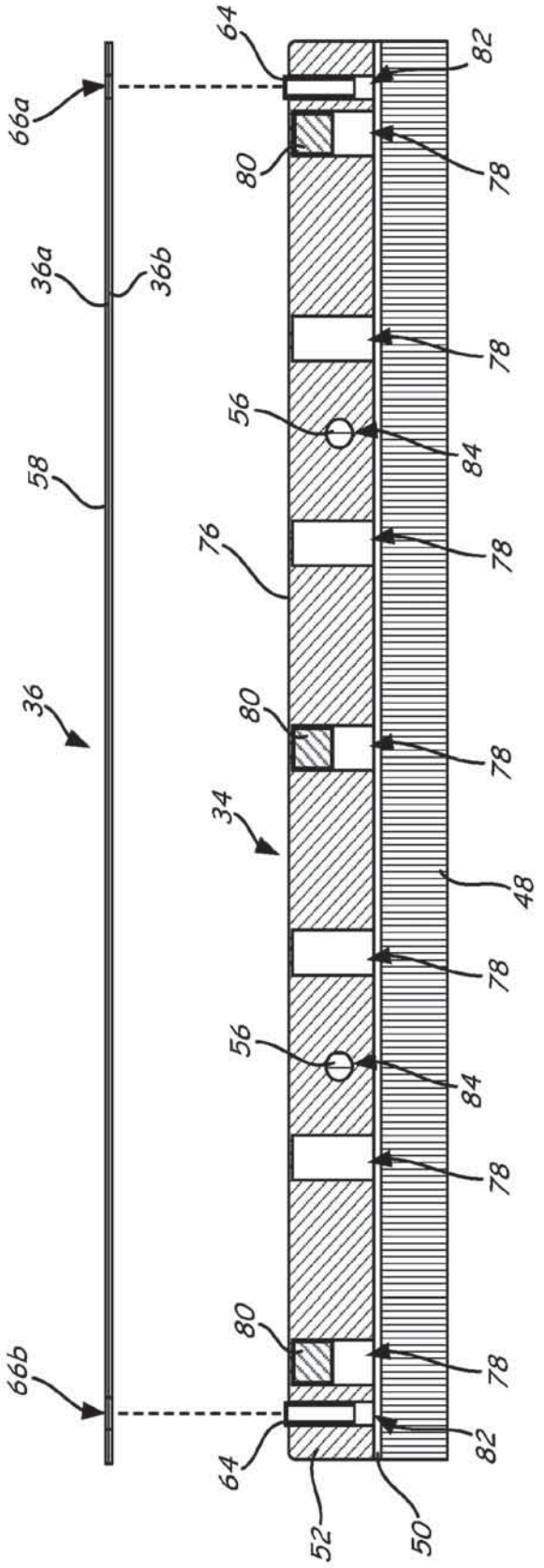

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FIG. 6

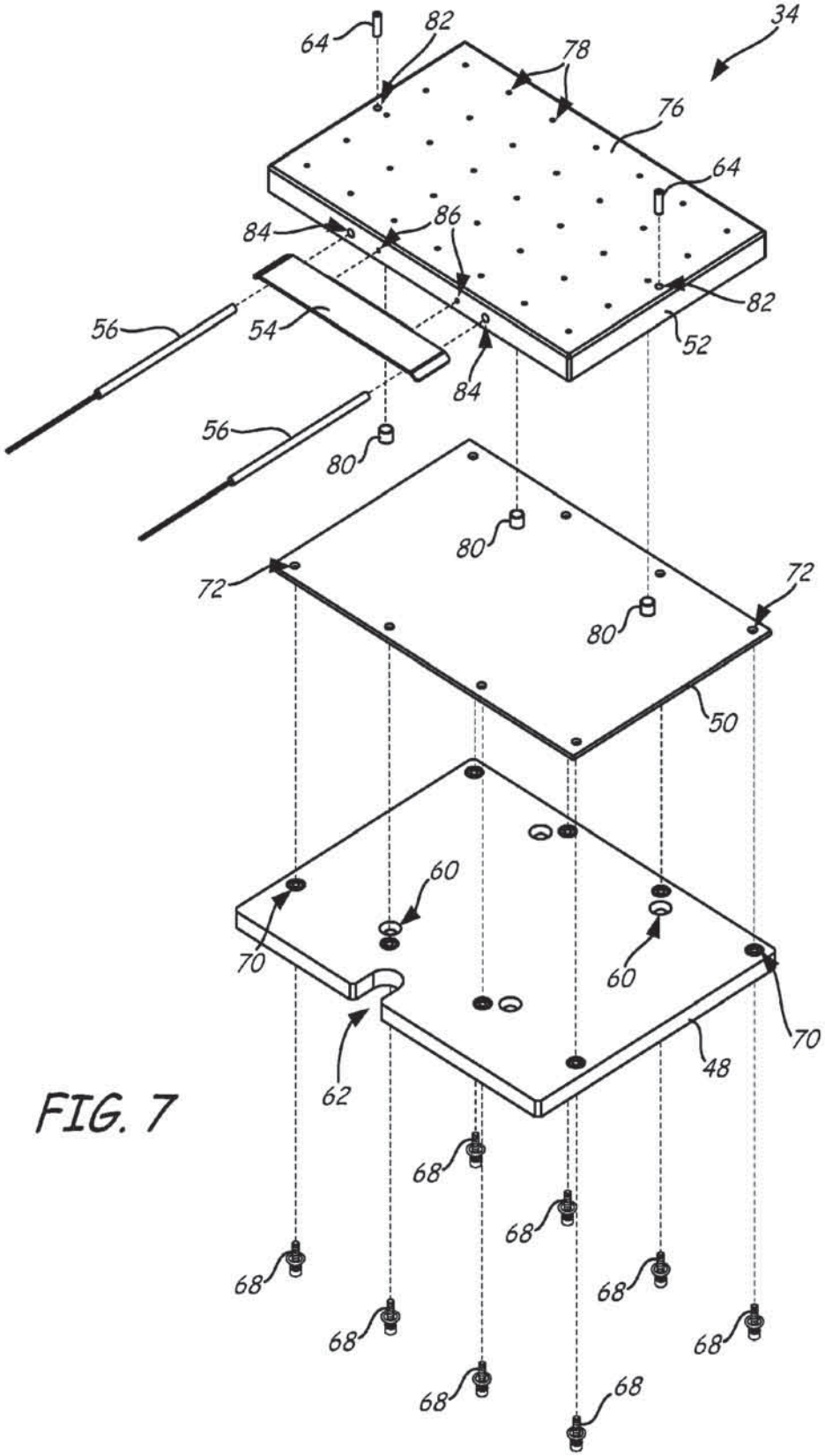

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FIG. 7

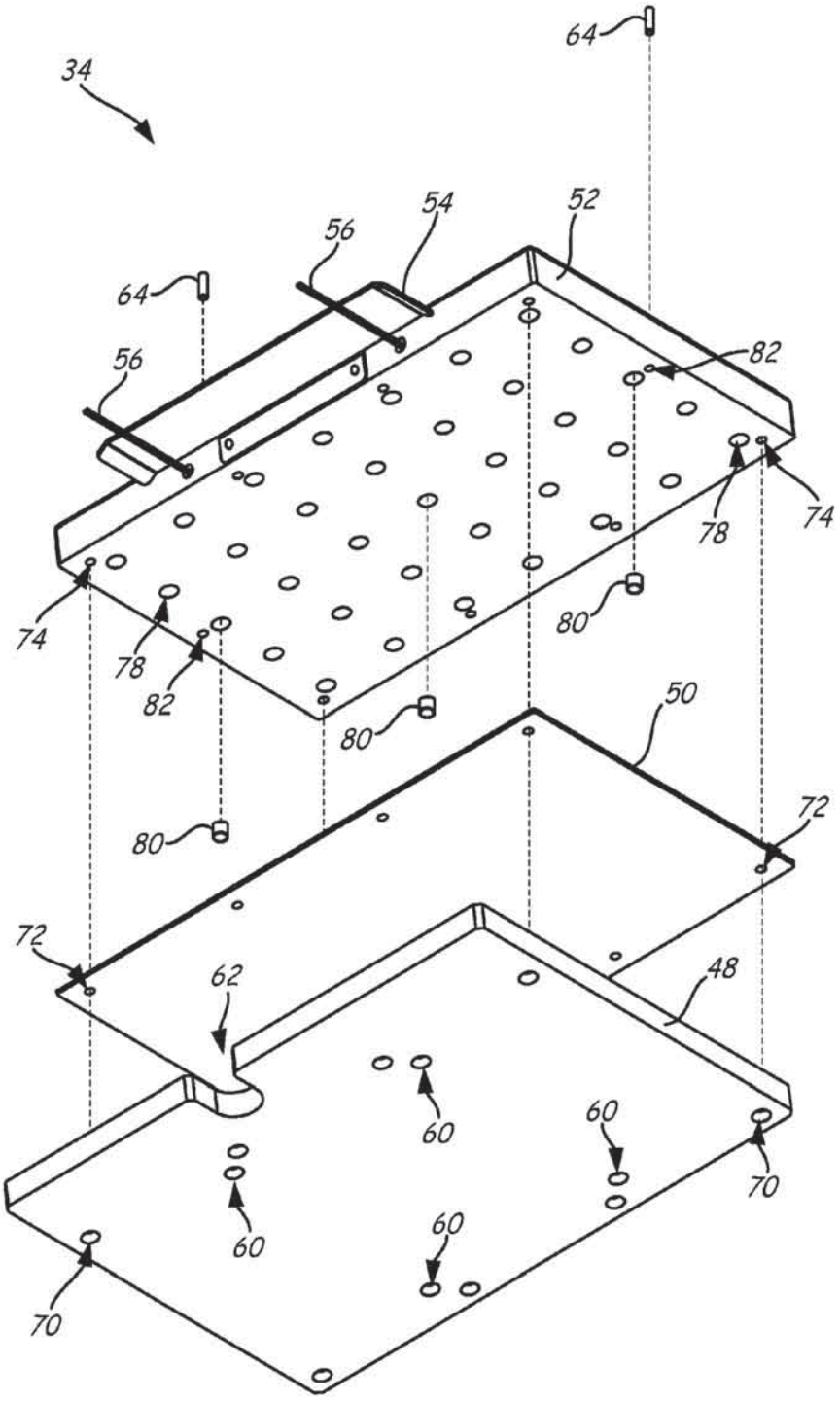

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FIG. 8

MAGNETIC PLATEN ASSEMBLY FOR ADDITIVE MANUFACTURING SYSTEM

BACKGROUND

The present disclosure relates to additive manufacturing systems for printing three-dimensional (3D) parts and support structures. In particular, the present disclosure relates to build sheets for receiving printed 3D parts and support structures in additive manufacturing systems.

Additive manufacturing systems are used to build 3D parts from digital representations of the 3D parts (e.g., AMF and STL format files) using one or more additive manufacturing techniques. Examples of commercially available additive manufacturing techniques include extrusion-based techniques, ink jetting, selective laser sintering, powder/binder jetting, electron-beam melting, and stereolithographic processes. For each of these techniques, the digital representation of the 3D part is initially sliced into multiple horizontal layers. For each sliced layer, a tool path is then generated, which provides instructions for the particular additive manufacturing system to form the given layer.

For example, in an extrusion-based additive manufacturing system, a 3D part or model may be printed from a digital representation of the 3D part in a layer-by-layer manner by extruding a flowable part material. The part material is extruded through an extrusion tip carried by a print head of the system, and is deposited as a sequence of roads on a substrate in an x-y plane. The extruded part material fuses to previously deposited part material, and solidifies upon a drop in temperature. The position of the print head relative to the substrate is then incremented along a z-axis (perpendicular to the x-y plane), and the process is then repeated to form a 3D part resembling the digital representation.

In fabricating 3D parts by depositing layers of a part material, supporting layers or structures are typically built underneath overhanging portions or in cavities of objects under construction, which are not supported by the part material itself. A support structure may be built utilizing the same deposition techniques by which the part material is deposited. The host computer generates additional geometry acting as a support structure for the overhanging or free-space segments of the 3D part being formed, and in some cases, for the sidewalls of the 3D part being formed. The support material adheres to the part material during fabrication, and is removable from the completed 3D part when the printing process is complete.

In two-dimensional (2D) printing, electrophotography (i.e., xerography) is a technology for creating 2D images on planar substrates, such as printing paper and transparent substrates. Electrophotography systems typically include a conductive support drum coated with a photoconductive material layer, where latent electrostatic images are formed by electrostatic charging, followed by image-wise exposure of the photoconductive layer by an optical source. The latent electrostatic images are then moved to a developing station where toner is applied to charged areas, or alternatively to discharged areas of the photoconductive insulator to form visible images. The formed toner images are then transferred to substrates (e.g., printing paper) and affixed to the substrates with heat and/or pressure.

SUMMARY

An aspect of the present disclosure is directed to an additive manufacturing system for printing a 3D part. The additive manufacturing system includes a printing mechanism (e.g., an electrophotography engine, a print head, etc. . . .) configured to print layers of the 3D part and a platen assembly. The platen assembly includes a platen plate, which preferably mounted to a gantry mechanism of the additive manufacturing system, and having a top surface, and one or more magnets secured to the platen plate and configured to generate one or more magnetic fields at the top surface of the platen plate. The platen assembly is configured to magnetically couple a build sheet to the top surface of the platen plate due to the one or more generated magnetic fields, where the magnetically-coupled build sheet is configured to receive the printed layers from the printing mechanism.

Another aspect of the present disclosure is directed to a platen assembly for use in an additive manufacturing system, which includes a chuck portion and a plurality of build sheets. The chuck portion includes a platen plate that has a top surface, a plurality of first openings disposed below the top surface, and at least one second opening disposed below the top surface. The chuck portion also includes a plurality of magnets secured in the plurality of first openings in the platen plate, where the plurality of secured magnets are configured to generate magnetic fields at the top surface of the platen plate. The chuck portion also includes at least one heating element disposed in the at least one second opening in the platen plate. The build sheets are each configured to interchangeably couple to the top surface of the platen plate due to the generated magnetic fields, and each have a receiving surface to receive printed layers of a 3D part and/or support structure.

Another aspect of the present disclosure is directed to a method for using a platen assembly in an additive manufacturing system. The method includes placing a first build sheet onto a top surface of a platen plate that is operably mounted to a gantry mechanism of the additive manufacturing system, magnetically coupling the placed first build sheet to the top surface of the platen plate, and printing layers of a 3D part onto the magnetically-coupled first build sheet. The method also includes removing the first build sheet with the printed 3D part from the top surface of the platen plate, and flexing the first build sheet to delaminate the 3D part from the first build sheet. The method may also include placing a second build sheet onto the top surface of the platen plate, magnetically coupling the placed second build sheet to the top surface of the platen plate, and printing layers of a second 3D part onto the magnetically-coupled second build sheet.

DEFINITIONS

Unless otherwise specified, the following terms as used herein have the meanings provided below:

The terms "preferred" and "preferably" refer to embodiments of the invention that may afford certain benefits, under certain circumstances. However, other embodiments may also be preferred, under the same or other circumstances. Furthermore, the recitation of one or more preferred embodiments does not imply that other embodiments are not useful, and is not intended to exclude other embodiments from the inventive scope of the present disclosure.

Directional orientations such as "above", "below", "top", "bottom", and the like are made with reference to a direction along a printing axis of a 3D part. In the embodiments in which the printing axis is a vertical z-axis, the layer-printing direction is the upward direction along the vertical z-axis. In these embodiments, the terms "above", "below", "top", "bottom", and the like are based on the vertical z-axis.

However, in embodiments in which the layers of 3D parts are printed along a different axis, the terms "above", "below", "top", "bottom", and the like are relative to the given axis.

The term "providing", such as for "providing a material" and the like, when recited in the claims, is not intended to require any particular delivery or receipt of the provided item. Rather, the term "providing" is merely used to recite items that will be referred to in subsequent elements of the claim(s), for purposes of clarity and ease of readability.

Unless otherwise specified, temperatures referred to herein are based on atmospheric pressure (i.e. one atmosphere).

The terms "about" and "substantially" are used herein with respect to measurable values and ranges due to expected variations known to those skilled in the art (e.g., limitations and variabilities in measurements).

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a front view of an example electrophotography-based additive manufacturing system for printing 3D parts and support structures with a platen assembly of the present disclosure.

FIG. **2** is a schematic front view of a layer transfusion assembly of the system, which includes the platen assembly of the present disclosure.

FIG. **3** is a top isometric view of the platen assembly.

FIG. **4** is a bottom isometric view of the platen assembly.

FIG. **5** is a top isometric view of the platen assembly with a build sheet removed from a chuck portion of the platen assembly.

FIG. **6** is a sectional view of Section **6-6** taken in FIG. **5**, illustrating magnet placements in the chuck portion.

FIG. **7** is a top isometric exploded view of the chuck portion of the platen assembly.

FIG. **8** is a bottom isometric exploded view of the chuck portion of the platen assembly.

DETAILED DESCRIPTION

The present disclosure is directed to a platen assembly for use in additive manufacturing systems, such as electrophotography-based additive manufacturing systems, extrusion-based additive manufacturing systems, and jetting-based additive manufacturing systems, to print 3D parts and support structures. In particular, the platen assembly of the present disclosure includes a chuck portion configured to magnetically retain removable and interchangeable build sheets during printing operations.

Additive manufacturing systems typically print 3D parts and support structures in a layer-by-layer manner onto build substrates, which function as receiving surfaces for the printed layers. This typically involves printing a base layer of the part and/or support material onto the build substrate, and then printing the desired 3D part and support structure on top of the base layers. An example of this application is discussed in LaBossiere et al., U.S. patent application Ser. No. 13/909,294, entitled "Platen Planarizing Process For Additive Manufacturing System".

A build substrate is typically a plastic component, such as an injection-molded tray or a thin plastic film, with surface energies and/or surface roughness tailored to achieve good adhesion with the first printed layer. Good adhesion is beneficial for anchoring the printed layers, thereby reducing curl and part distortions during the printing process.

However, this good adhesion can also present an issue with removal of the printed 3D part and support structure from the build substrate, particularly where the first printed layer is derived from a part material or other non-soluble material. As such, the build substrate is preferably flexible enough to allow a user to peel the build substrate from the base of the printed 3D part/support structure.

In particular, the flexing of the build substrate amplifies the stresses induced at the bending line of action, causing delamination of the 3D part from its base layers, or delamination of the base layers from the build substrate. Earlier systems incorporated thick inflexible build platens, making removal of thick stiff 3D parts with large base areas very difficult. In fact, the only effective solution of removal in this case involved prying the 3D part off with crow bar-like device or chisel, which could damage the 3D part or platen. Otherwise, the 3D part and platen would be removed from the system, and a band saw would be used to cut the thick 3D part from the inflexible base.

Flexible plastic trays, such as those disclosed in Dunn et al., U.S. Pat. No. 7,127,309, can be reliably mounted in additive manufacturing systems with snap features that hold the trays in a reasonably flat condition. These trays are produced by injection molding and can be treated as a disposable item, although at times they may be reused if the first printed layers can be cleanly removed from the surfaces. These trays are vertically stiff only at the snap feature locations, and are springy in the vertical direction in between these mounting points.

Alternatively, in other systems, such as those disclosed in Skubic et al., U.S. Pat. No. 8,153,183, thin plastic films can be used, which are typically held by vacuum onto flat stiff metal platens. This maintains the thin film in a flat condition during the printing operation. However, in some applications, the cost and complexity of adding a vacuum system can be a detracting feature, and can potentially be sensitive to debris contamination between the film and the platen. This can cause weak or total loss of suction, allowing the film to undesirably move during the printing process. Additionally, vacuum systems can be noisy, which can be undesirable in some applications.

In comparison, the platen assembly of the present disclosure, which incorporates a chuck portion that magnetically couples to removable and interchangeable build sheets, provides several unique advantages over build substrates currently used in the industry. As discussed below, the magnetic coupling allows low-cost and reliable build sheets to be used without also requiring vacuum systems, which can substantially reduce the complexity of the additive manufacturing system.

The following discussion of the platen assembly of the present disclosure is made with reference to use in an electrophotography-based additive manufacturing system, which is a preferred system. However, the magnetic platen assembly may also be utilized with any suitable additive manufacturing system that includes one or more printing mechanisms for printing layers of 3D parts and/or support structures, where good substrate adhesion is desired.

For instance, the platen assembly is also advantageous for use in extrusion-based additive manufacturing systems, such as those developed by Stratasys, Inc., Eden Prairie, Minn. under the trademark "FDM". In these embodiments, examples of suitable extrusion-based additive manufacturing systems include those disclosed in Crump, U.S. Pat. No. 5,121,329; Crump et al., U.S. Pat. No. 5,503,785; Swanson et al., U.S. Pat. No. 6,004,124; LaBossiere, et al., U.S. Pat. Nos. 7,384,255 and 7,604,470; Leavitt, U.S. Pat. No. 7,625,

200; Batchelder et al., U.S. Pat. No. 7,896,209; Comb et al., U.S. Pat. No. 8,153,182; and Swanson et al., U.S. Pat. No. 8,419,996.

Alternatively, the platen assembly may also be useful in jetting-based additive manufacturing systems, such as those described in Kritchman et al., U.S. Pat. No. 8,323,017. As used herein, the term "printing mechanism" refers to the component(s) used to print layers of the 3D parts and/or support structures onto the platen assembly. For example, the printing mechanism may include one or more electrophotography engines and/or a transfer medium (for electrophotography-based additive manufacturing systems), one or more print heads (for extrusion-based and jetting-based additive manufacturing systems, powder dispensing mechanisms and/or laser or jetting heads (for selective laser sintering and binder-jetting additive manufacturing systems), and the like.

FIGS. **1** and **2** illustrate system **10**, which is an example electrophotography-based additive manufacturing system for printing 3D parts and associated support structures with the use of the platen assembly of the present disclosure. As shown in FIG. **1**, system **10** includes a pair of EP engines **12***p* and **12***s*, belt transfer assembly **14**, and layer transfusion assembly **16**. Examples of suitable components and functional operations for system **10** include those disclosed in Hanson et al., U.S. Publication Nos. 2013/0077996 and 2013/0077997, and in Comb et al., U.S. Publication Application Nos. 2013/0186549 and 2013/0186558, where layer transfusion assembly **16** is uniquely designed to incorporate the platen assembly of the present disclosure.

EP engines **12***p* and **12***s* are imaging engines for respectively imaging or otherwise developing layers of part and support materials, where the part and support materials are each preferably engineered for use with the particular architecture of EP engine **12***p* or **12***s*. The imaged layers may then be transferred to belt transfer assembly **14** (or other transfer medium), and carried to layer transfusion assembly **16** to print the 3D parts and associated support structures in a layer-by-layer manner.

In the shown embodiment, belt transfer assembly **14** includes transfer belt **18** and one or more belt drive mechanisms, belt drag mechanisms, loop limit sensors, idler rollers, belt cleaners, and the like, which are configured to maintain tension on belt **18** while belt **18** rotates in the rotational direction of arrows **20**. Belt **18** is a transfer medium for transferring the developed successive layers from EP engines **12***p* and **12***s* to layer transfusion assembly **16**.

System **10** also includes controller **22**, which is one or more control circuits, microprocessor-based engine control systems, and/or digitally-controlled raster imaging processor systems, and which is configured to operate the components of system **10** in a synchronized manner based on printing instructions received from host computer **24**. Host computer **24** is one or more computer-based systems configured to communicate with controller **22** to provide the print instructions (and other operating information). For example, host computer **24** may transfer information to controller **22** that relates to the sliced layers of the 3D parts and support structures, thereby allowing system **10** to print the 3D parts and support structures in a layer-by-layer manner.

Controller **22** preferably rotates EP engines **12***p* and **12***s* at the same rotational rates that are synchronized with the line speed of belt **18**. This allows system **10** to develop and transfer layers in coordination with each other from separate developer images. In particular, each part layer may be transferred to belt **18** with proper registration with each support layer to preferably produce a combined part and support material layer. As can be appreciated, some layers transferred to layer transfusion assembly **16** may only include the support material or may only include the part material, depending on the particular support structure and 3D part geometries and layer slicing.

FIG. **2** illustrates an example embodiment for layer transfusion assembly **16**, which includes platen assembly **26** of the present disclosure, and may also include one or more of heated nip roller **28**, pre-heaters **30***a* and **30***b*, post-fuse units **32** (e.g., post-fuse heaters and/or cooling units), and any other suitable component, which may function as disclosed in Hanson et al., U.S. Publication Nos. 2013/0077996 and 2013/0077997, and in Comb et al., U.S. Publication Nos. 2013/0186549 and 2013/0186558.

As discussed further below, platen assembly **26** includes a rigid chuck portion **34** that magnetically retains replaceable and interchangeable build sheets **36**. Each build sheet **36** is configured to receive the part and/or support layers from belt **18** for printing 3D parts and support structures (e.g., 3D part **38** and support structure **40**) in a layer-by-layer manner.

In the shown embodiment, platen assembly **26** is supported by gantry **42**, which is a gantry mechanism configured to move platen assembly **26** along the z-axis and the x-axis to produce a reciprocating rectangular pattern, where the primary motion is back-and-forth along the x-axis (illustrated by broken lines **44**). Gantry **42** may be operated by motor **46** based on commands from controller **22**, where motor **46** may be an electrical motor, a hydraulic system, a pneumatic system, or the like. In some alternative systems, platen assembly **26** may be mounted to a stationary mount rather than gantry **42**.

To ensure that 3D part **38** and support structure **40** are printed with good and accurate precision, the build sheet **36** needs to remain flat and preferably does not move during the printing operation. However, the rolling action of nip roller **28** generates roller pressure, which can cause thin plastic sheets to creep or walk (much like pie dough) during a printing operation. Additionally, and just as importantly, curling forces from the printed layers can cause thin plastic sheets to pull upward in a potato chip-like manner. In fact, in some additive manufacturing systems, the curling forces can be great enough to even pull up steel plates that have cross-sectional areas of about 4-feet and about ¾-inch thicknesses. If these situations occur, the resulting part quality can be compromised. Furthermore, injection molded trays are less desirable for use in system **10** since they are typically flexible between mounting points, which can deflect under the pressure of nip roller **28**, causing non-uniformities in the part creation.

Accordingly, chuck portion **34** is uniquely engineered to hold a build sheet **36** in a secure and flat manner that prevents the build sheet **36** from creeping or walking under the rolling action of nip roller **28**, and also provides a sufficient restraining pressure to prevent curling forces from the printed layers from pulling build sheet **36** upward from its planar orientation. As discussed below, chuck portion **34** magnetically holds the build sheet **36** in a manner that eliminates any obstructions above the build surface, which could otherwise interfere with nip roller **28** during printing operations.

FIGS. **3-8** illustrate an example embodiment for platen assembly **26**. As shown in FIGS. **3** and **4**, chuck portion **34** of platen assembly **26** includes gantry adapter **48**, insulator **50**, platen plate **52**, heat shield **54**, and a pair of heating

elements **56**. Additionally, build sheet **36** of platen assembly **26** is an example of a replaceable and interchangeable build sheet for use with chuck portion **34**, and includes top receiving surface **58**. Receiving surface **58** is the surface that receives the printed layers of 3D part **38** and/or support structure **40**.

Gantry adapter **48** is base component that is preferably fabricated from one or more metallic materials (e.g., aluminum or stainless steel), and is configured to securely mount platen assembly **26** to gantry **42** with four mounting bores **60** (shown in FIG. **4**) or other suitable types and numbers of mounting mechanisms. Gantry adapter **48** may also include an optional notch **62**, which may be used to route cables for layer transfusion assembly **16** in a convenient manner.

Insulator **50** is one or more liners or standoffs disposed between gantry adapter **48** and platen plate **52**, which may be derived from one or more thermally-insulating materials. In embodiments in which insulator **50** is a contiguous liner, insulator **50** preferably has similar thermal expansion coefficients to the material(s) of platen plate **52** (e.g., mica). In some preferred embodiments, insulator **50** may be a webbed or meshed liner, or, more preferably, includes standoffs to physically separate platen plate **52** from gantry adapter **48** and gantry **42** with air gaps. This thermally isolates platen plate **52** from gantry adapter **48** and gantry **42**, preventing or otherwise restricting heat generated at platen plate **52** from being drawn into gantry adapter **48** and gantry **42**.

Platen plate **52** is a heatable platen, preferably fabricated from one or more metallic materials (e.g., aluminum), and is configured to retain build sheet **36** by magnetic coupling, as discussed below. Additionally, platen plate **52** includes a pair of pins or dowels **64**, that extend through platen plate **52** and into opposing holes **66***a* and **66***b* in build sheet **36**, as also discussed below. As discussed further below pins **64** may be replaced with other suitable raised members, such as raised bosses or ribs.

In alternative embodiments, one or more of gantry adapter **48**, insulator **50**, and platen plate **52** may be integrally fabricated together as a single component. For example, gantry adapter **48** and platen plate **52** may be a single component that where the gantry adapter **48** portion is offset from the platen plate **52** portion by thermally-insulating standoffs. Furthermore, in other embodiments, gantry adapter **48** may be replaced with other connective mechanisms to operably secure platen plate **52** to gantry **42** (or other gantry assembly).

In further alternative embodiments, one or more of liner **50**, heat shield **54**, and heating elements **56** may be omitted, such that platen plate **52** is not directly heated during a printing operation. For example, these components may be omitted when layer transfusion assembly **16** operates in a heated chamber. Alternatively, these components may be omitted when printing from low-temperature part and support materials (e.g., in room-temperature environment).

As shown in FIG. **4**, platen plate **52** is secured to gantry adapter **48** with eight fasteners **68** that extend through eight holes **70** in gantry adapter **48**, through eight holes in insulator **50** (referred to as holes **72**, shown below in FIG. **7**), and into eight holes in platen plate **52** (referred to as holes **74**, shown below in FIG. **8**). This secures platen plate **52** to gantry adapter **48**, with insulator **50** sandwiched therebetween, to prevent platen plate **52** from moving relative to gantry adapter **48**. This accordingly allows gantry **42** to move the entirety of platen assembly **26** together in the reciprocating rectangular pattern. While illustrated with eight fasteners and a corresponding number of holes, gantry adapter **48**, insulator **50**, and platen plate **52** may be secured together using any suitable mechanism.

Heat shield **54** is secured to a lateral edge of platen plate **52**, and is configured to prevent heat generated by heating elements **56** from radiating upwards from the lateral side of platen plate **52**. Heat shield **54** may be fabricated from any suitable material, such as metallic materials (e.g., aluminum) and/or high-temperature polymeric materials.

Heating elements **56** are a pair of electric heating elements configured to heat and maintain platen plate **52** at an elevated temperature, as discussed in Comb et al., U.S. Publication Nos. 2013/0186549 and 2013/0186558. The particular heating temperature may vary depending on the compositions of the part and support materials. For example, when printing with an ABS part material, heating elements **56** may heat platen plate **52** to about 110° C.

As shown in FIG. **5**, build sheet **36** is a removable and interchangeable sheet for receiving the printed part and support layers of 3D part **38** and support structure **40** (or multiple 3D parts and support structures). In a preferred embodiment, build sheet **36** is a multiple-layer sheet having a top film **36***a* laminated on or otherwise adhered to a metallic base sheet **36***b*. Base sheet **36***b* is derived from one or more ferromagnetic materials, such as one or more metallic materials (e.g., steel), to assist in the magnetic coupling to platen plate **52**.

Top film **36***a* may be derived from one or more polymeric coatings, tapes, or other lamina, which may be adhered to base sheet **36***b*. For example, a polycarbonate top film **36***a* may be adhered with a high-temperature adhesive to a steel base sheet **36***b*, which is advantageous for use with ABS and polycarbonate part materials due to their similar glass transition temperatures.

For use with higher-temperature part materials, such as polyetherimide part materials, top film **36***a* may be applied to base sheet **36***b* as a high-temperature tape, such as polyimide tapes commercially available under the trademark "KAPTON" from E. I. du Pont de Nemours and Company, Wilmington, Del. Alternatively, for use with lower temperature part materials, such as polylactic acid part materials, tapes derived from polymeric materials having lower glass transition temperatures may be applied to base sheet **36***b*.

The top film **36***a*, as an adhesive tape or other coating adhered to base sheet **36***b*, preferably exhibits good adhesion to the part and/or support materials used in system **10**. To this end, top film **36***a* may optionally be surface treated or otherwise conditioned to increase its adhesive properties (e.g., texturing). As mentioned above, good adhesion is beneficial for anchoring the printed layers, thereby reducing curl and part distortions during the printing process.

Build sheet **36** preferably has an overall thickness that can vary based on a desired stiffness for use in system **10**, while also enabling efficient peeling of the printed layers. Suitable thicknesses for base sheet **36***b* may range from about 5 mils to about 100 mils, and more preferably from about 5 mils to about 50 mils, and even more preferably from about 10 mils to about 30 mils. As discussed below, these thicknesses for build sheet **36***b* preferably balance the competing factors of (i) providing a sufficient magnetic coupling, and (ii) providing sufficient flexibility to remove 3D part **38** and support structure **40** after a printing operation is completed. Correspondingly, suitable thicknesses for top film **36***a* may range from about 1 mil to about 30 mils, more preferably from about 5 mils to about 20 mils, and even more preferably from about 5 mils to about 10 mils.

As further shown in FIG. **5**, build sheet **36** may be placed onto a top surface of platen plate **52**, referred to as top

surface **76**. In particular, build sheet **36** may be aligned such that pins (or other raised members) **64** insert into holes **66***a* and **66***b* when build sheet **36** is flush against top surface **76**. Hole **66***a* preferably provides a close tolerance fit with its associated pin **64** to fix the position of build sheet **36** relative to platen plate **52**. Hole **66***b*, however, is preferably an elongated slot, where the engagement between hole **66***b* and its associated pin **64** preferably prevents rotation of build sheet **36** around hole **66***a*, while also allowing build sheet **36** to expand as it is heated by platen plate **52** and heating elements **56**.

In some embodiments, platen plate **52** may include additional numbers of pins **64** (i.e., two or more pins **64**) and build sheet **36** may include additional numbers of holes corresponding to holes **66***a* and/or hole **66***b* (i.e., two or more holes **66***a*/**66***b*). Pins **64** and holes **66***a* and **66***b* are preferably located on the peripheral edges to maximize the printable surface area on receiving surface **58**. As mentioned above, pins **64** may be replaced with other suitable members that are raised above top surface **76**, which may function in a similar manner to pins **64** (e.g., raised bosses or ribs).

Top surface **76** is a substantially planar surface that includes surface holes that extend into an array of counterbores **78**, as shown in FIG. **6** (also shown below in FIG. **8**). As used herein, the term "planar surface" refers to a surface that is flat, but may also include small holes (e.g., for counterbores **78**), grooves, and the like. Counterbores **78** provide convenient locations for inserting a plurality of magnets **80**, which may be secured in counterbores **78** in any suitable manner (e.g., with an adhesive). In the shown example, platen assembly **26** includes three magnets **80** to magnetically couple build sheet **36** to top surface **76** of platen plate **52**. However, in alternative embodiments, platen assembly **26** may include any suitable number of magnets **80** for customizing the magnetic coupling, where each magnet is preferably capable of withstanding the heated temperature of platen plate **52**.

Furthermore, the array of counterbores **78** (best shown below in FIG. **8**) allows magnets **80** to be positioned in any suitable configuration, where the holes in top surface **76** are optional holes to facilitate the removal of magnets **80**, if desired. As such, a user may customize the locations of magnets **80** relative to platen plate **52**. A suitable application for customizing the locations of magnets **80** is when using build sheets **36** having different sizes (e.g., larger or smaller build sheets **36**).

In an alternative embodiment, platen plate **52** may have a fixed number of counterbores **78** (or other openings) to permanently receive and retain the same number of magnets **80** in a non-customizable manner (e.g., three counterbores **78** and three magnets **80**). In further alternative embodiments, counterbores **78** may be replaced with any suitably-shaped slot for receiving and retaining magnets **80**. Correspondingly, magnets **80** may have different shapes to be received the reciprocating slots of platen plate **52**, such as rectangular shapes, round shapes, bar shapes, and the like.

In yet another alternative embodiment, counterbores **78** (or other suitable slots) may extend through top surface **76** such that magnets **80** may be inserted through top surface **76** (rather than through the bottom surface, as shown in FIGS. **6-8**). In this case, the top faces of the inserted magnets **80** may be flush with top surface **76** to maintain a substantially level surface for magnetically coupling build sheets **36**.

In a first embodiment, magnets **80** are permanent magnets that generate persistent magnetic fields at top surface **76**. These magnetic fields provide the magnetic coupling required to hold build sheet **36** flush against top surface **76**. In this case, build sheet **36** may be removed from top surface **76** (e.g., after a printing operation is completed) by peeling or otherwise pulling build sheet **36** with a pulling force that is greater than the attraction force of the generated magnetic fields.

In another embodiment, magnets **80** are electromagnets configured to receive electrical currents from system **10** to generate the magnetic fields. In this embodiment, each magnet **80** may be a coil electrically connected to system **10** via one or more electrical lines (not shown). The coil may optionally be wrapped around a ferromagnetic material (e.g., steel) to increase the magnetic coupling strength. This embodiment is beneficial for generating a strong magnetic coupling during a printing operation (by inducing an electrical current through the coils of magnets **80**), while also allowing the magnetic field to be disabled or otherwise reduced after the printing operation (by stopping the electrical current) to readily remove build sheet **36**.

Additionally, magnets **80** as electromagnets may optionally be used to generate heat for platen plate **52** and build sheet **36** via electrical resistance heating. For example, the voltage and resistance may be sized to produce the desired levels of power. In this use, heating elements **56** may be optionally omitted, or may be used in addition to the electrical resistance heating.

In either embodiment, the attraction strength of the magnetic coupling during a printing operation is preferably great enough to prevent build sheet **36** from moving laterally relative to top surface **76**, and to prevent build sheet **36** from pulling upward from its planar orientation against top surface **76** (e.g., due to curling forces). However, there is a limit to the attraction strength that can be generated per unit volume of base sheet **36***b*. In effect, assuming an excess number of magnets **80**, the strength of the magnetic coupling is typically limited by the cross-sectional area and thickness of base sheet **36***b*.

Accordingly, the attraction strength can be increased to a given extent by increasing the number of magnets **80** below the cross-sectional area of base sheet **36***b*. However, when this is maxed out, the thickness of base sheet **36***b* becomes the limiting factor, where a greater thickness for base sheet **36***b* may provide a stronger magnetic coupling. However, a greater thickness for base sheet **36***b* may also detrimentally affect its flexibility, which can potentially reduce the ability to peel 3D part **38** and support structure **40**. Thus, the thickness of base sheet **36***b*, such as the suitable and preferred thicknesses discussed above, is preferably selected to balance these competing factors.

In general, printing operations that generate lower curling forces may utilize thinner build sheets **36** and/or more sparse magnetic fields. In comparison, printing operations that generate higher curling forces preferably increase the densities of the magnetic fields (e.g., more magnets), and, if necessary, also increase the thickness of build sheet **36**, where the strength of the magnetic coupling typically follows a non-linear relationship with the thickness of build sheet **36**.

As further shown in FIG. **6**, platen plate **52** also includes a pair of opposing bores **82**, which are the locations in which pins **64** are inserted and retained such that the top ends of pins **64** extend upward beyond the plane of top surface **76**. This allows pins **64** to insert into holes **66***a* and **66***b* of build sheet **36**. In alternative embodiments, pins **64** may be integrally formed with platen plate **52** such that pins **64** extend above top surface **76** in the same manner. Preferably, the top ends of pins **64** do not extend above receiving surface **58** of build sheet **36** when build sheet **36** rests on top surface

76 of platen plate 52. This provides a planar, unobstructed receiving surface 58 for nip roller 28 to roll across.

Similarly, the other components of platen assembly 26, including heat shield 54, preferably remain lower than the height of receiving surface 58 of build sheet 36. Accordingly, all of the holding mechanisms for retaining build sheet 36 to platen plate 52 (i.e., magnets 80 and pins 64) remain below the height of receiving surface 58. This prevents any interference with the motion of nip roller 28 of system 10, or with any extrusion tips or jetting nozzles in extrusion-based and jetting-based additive manufacturing systems.

As also shown in FIG. 6, heating elements 56 extend through lateral openings 84 in platen plate 52, preferably in a tight-fit manner, to allow heating elements 56 to conductively heat platen plate 52. The relative engagements between the components of platen assembly 26 are further shown in FIGS. 7 and 8. For example, as shown in FIG. 7, heat shield 54 may be mounted to the lateral side of platen plate 52 with lateral holes 86.

Platen assembly 26 may be assembled by inserting heating elements 56 through lateral openings 84 of platen plate 52, securing magnets 80 in counterbores 78, and inserting pins 64 into holes 82. Insulator 50 may positioned between gantry adapter 48 and platen plate 52, and the stack may be secured together with fasteners 68. Heat shield 54 may also be connected to platen plate 52 with lateral holes 86, and the resulting platen assembly 26 may be mounted to gantry 42 via mounting bores 60. Heating elements 56 may then be connected to electrical lines of system 10 to receive electrical power during operation.

Once installed in system 10, a build sheet 36 may be placed on top surface 76 of platen plate 52 such that pins 64 insert into holes 66*a* and 66*b* of build sheet 36. When build sheet 36 is placed on top surface 76, magnets 80 securely hold build sheet 36 down against top surface 76, where pins 64 and holes 66*a* and 66*b* prevent movement of build sheet 36 in the plane of top surface 76. Electrical power may also be relayed to heating elements 56 to heat platen plate 52 and build sheet 36 to a desired temperature, as discussed above.

During a printing operation, belt 18 may carry each printed layer past pre-heater 30*a*, which may heat the printed layer and the associated region of belt 18 to a desired transfer temperature. Additionally, gantry 42 may move platen assembly 26 in a reciprocating rectangular pattern 44. In particular, gantry 26 may move platen assembly 26 along the x-axis below, along, or through pre-heater 30*b*. Pre-heater 30*b* heats the top surfaces of 3D part 38 and support structure 40 to an elevated temperature, such as a desired transfer temperatures of the part and support materials. As discussed in Comb et al., U.S. Publication Nos. 2013/0186549 and 2013/0186558, heaters 30*a* and 30*b* may heat the printed layers and the top surfaces of 3D part 38 and support structure 40 to about the same temperatures to provide a consistent transfusion interface temperature.

The continued rotation of belt 18 and the movement of platen assembly 26 align the heated layer on belt 18 with the heated top surfaces of 3D part 38 and support structure 40 with proper registration along the x-axis. Gantry 42 may continue to move platen assembly 26 along the x-axis, at a rate that is synchronized with the rotational rate of belt 18 in the direction of arrow 20 (i.e., the same directions and speed). This causes belt 18 to rotate around nip roller 28 to nip belt 18 and the heated layer on belt 18 against the top surfaces of 3D part 38 and support structure 40. This presses the heated layer between the heated top surfaces of 3D part 38 and support structure 40 at the location of nip roller 28, which at least partially transfuses heated layer to the top layers of 3D part 38 and support structure 40.

As the transfused layer passes the nip of nip roller 28, belt 18 wraps around nip roller 28 to separate and disengage from platen assembly 26. This assists in releasing the transfused layer from belt 18, allowing the transfused layer to remain adhered to 3D part 38 and support structure 40. As can be appreciated, the relative movement between platen assembly 26 and nip roller 28 can cause substantial lateral pressures to be applied to build sheet 36, particularly when printing the first several layers of 3D part 38 and support structure 40.

However, the magnetic coupling, along with the insertion of pins 64 into holes 66*a* and 66*b*, allow build sheet 36 to withstand these lateral pressures without moving relative to platen plate 52, and to remain flush against top surface 76 of platen plate 52. This is also attainable without requiring the use of a vacuum system. As such, system 10 may be free of any vacuum system for securing build sheet 36 to platen plate 52.

After the transfused layer is released from belt 18, gantry 42 may continue to move platen assembly 26 along the x-axis to one or more post-fuse units 32 (e.g., post-fuse heaters and/or cooling units), as also discussed in Comb et al., U.S. Publication Nos. 2013/0186549 and 2013/0186558. Gantry 42 may then actuate platen assembly 26 downward, and move platen assembly 26 back along the x-axis to a starting position along the x-axis, following the reciprocating rectangular pattern 44.

Platen assembly 26 desirably reaches the starting position for proper registration with the next printed layer. In some embodiments, gantry 42 may also actuate platen assembly 26 and 3D part 38/support structure 40 upward for proper registration with the next printed layer. The same process may then be repeated for each remaining printed layer of 3D part 38 and support structure 40.

After the printing operation is completed, build sheet 36, with the resulting 3D part 38 and support structure 40, may be removed from platen plate 52. In embodiments in which magnets 80 are permanent magnets, this may be achieved by peeling or otherwise pulling build sheet 36 apart from platen plate 52 with enough upward force to overcome the magnetic coupling of magnets 80. Alternatively, in embodiments in which magnets 80 are electromagnets, the electrical current relayed to magnets 80 may be stopped, thereby disabling or otherwise reducing the magnetic coupling. In this case, build sheet 36 may then be readily removed from top surface 76 with little effort.

After removal from platen plate 52, the thin, flexible nature of build sheet 36 allows 3D part 38 and support structure 40 to be removed by flexing build sheet 36. This flexing of build sheet 36 amplifies the stresses induced at the bending line of action, causing delamination of 3D part 38 and support structure 40 from its base part, or delamination of the base part from build sheet 36.

The removed 3D part 38 and support structure 40 may then undergo one or more post-printing operations. For example, support structure 40 derived from a soluble support material may be sacrificially removed from 3D part 38, such as by using an aqueous-based solution (e.g., an aqueous alkali solution). Under this preferred soluble technique, support structure 40 may at least partially dissolve in the solution, separating it from 3D part 38 in a hands-free manner.

For a subsequent printing operation, the same or a new build sheet 36 may be placed on top surface 76 of platen plate 52. For instance, the previous build sheet 36 may be

recycled or otherwise discarded in an environmentally-friendly manner, and a new build sheet **36** may be placed on, and magnetically coupled to, top surface **76** in the same manner as discussed above for use in the subsequent printing operation.

Alternatively, if the previous 3D part **38** and support structure **40** cleanly are removed from the previous build sheet **36**, and the previous build sheet **36** retains its integrity, the same previous build sheet **36** may be reused. In some cases, the same previous build sheet **36** may also be reused by removing any residual printed layers from top film **36***a* to provide a clean receiving surface **58**. In a further alternative scenario, the previous top film **36***a* may be removed from base sheet **36***b*, and a new top film **36***a* may be applied to base sheet **36***b* (e.g., as a new adhesive tape or coating). This allows the previous base sheet **36***b* to be reused, if desired.

The replaceable nature of build sheet **36** also allows different build sheets **36** to be used with the same platen plate **52**, where the different build sheets **36** may have top films **36***a* derived from different materials, different thicknesses, and/or different receiving surfaces **58**. For example, the top films **36***a* of different build sheets **36** may include polymeric materials that are compositionally different (e.g., polycarbonates versus polyimides).

In most embodiments, the different build sheets **36** preferably have the same base sheets **36***b* to ensure the same magnetically coupling is achieved with platen plate **52**. For example, the base sheets **36***b* of different build sheets **36** may compositionally be the same or substantially the same (i.e., the same or substantially the same metallic materials). However, in some cases, the base sheets **36***b* may also be different, such as having different thicknesses (for customized flexing) and/or different metallic compositions to maintain good adhesion with different top films **36***a*, so long as they maintain good magnetic couplings to platen plate **52**.

Accordingly, build sheets **36** may be individually customized for use with particular part and support materials to improve adhesion and/or peeling characteristics. For example, a first build sheet **36** may have a polycarbonate-coating top film **36***a* for use with ABS and polycarbonate part materials, and a second build sheet **36** may have a polyimide-tape top film **36***a* for use with polyetherimide part materials. This customization provides in a unique advantage over generic build substrates that are universally used with multiple part and support materials, namely it provides a low-cost solution to individually tailor the adhesion and/or peeling characteristics to particular part and/or support materials.

The above-discussed steps for replaceably and interchangeably using one or more build sheets **36** with platen plate **52** may be performed in a manual or automated manner. In a manual process, a user may align and place each build sheet **36** onto top surface **76** of platen plate **52** prior to a printing operation. After the printing operation is completed, the user may the peel or otherwise pull the build sheet **36** with the printed 3D part **38** and support structure **40** apart from platen plate **52**, and replace the given build sheet **36** (or reuse the same build sheet **36**).

Alternatively, in an automated process, system **10** may include an automated mechanism to place each build sheet **36** onto top surface **76** of platen plate **52** prior to each printing operation, and to remove and replace the given build sheets **36** after each printing operation. Examples of suitable automated mechanisms for operating system **10** in this manner are disclosed in Swanson et al., U.S. patent application Ser. No. 13/791,005. For instance, system **10** may include a stack of multiple build sheets **36**, which may be individually placed onto platen plate **52** between each printing operation. This automated arrangement allows system **10** to perform multiple, successive printing operations in an automated manner with minimal or no user intervention, such as in a printing farm environment of multiple additive manufacturing systems.

Although the present disclosure has been described with reference to preferred embodiments, workers skilled in the art will recognize that changes may be made in form and detail without departing from the spirit and scope of the disclosure.

The invention claimed is:

1. An electrophotography-based additive manufacturing system for printing a three-dimensional part, the additive manufacturing system comprising:

a printing mechanism configured to print imaged layers of charged powder material to a moving belt; and a platen assembly comprising:

a platen plate having a top surface having a plurality of spaced apart members extending therefrom; and

one or more magnets secured to the platen plate and configured to generate one or more magnetic fields at the top surface of the platen plate; wherein the platen assembly is configured to magnetically couple a build sheet to the top surface of the platen plate due to the one or more generated magnetic fields and the plurality of spaced apart members are configured to be accepted by a plurality of apertures in the build sheet, and wherein the build sheet is configured to receive the printed layers from the printing mechanism wherein the platen assembly moves in a synchronized rate of speed with the imaged layer to transfer the imaged layer from the moving belt to the platen or previously printed part layers over time using heat and pressure.

2. The additive manufacturing system of claim **1**, and further comprising the build sheet, which comprises:

a base sheet comprising one or more ferromagnetic materials; and

a top film disposed on the base sheet and comprising one or more polymeric materials, wherein the top film defines a receiving surface for the build sheet to receive the printed layers and wherein the plurality of apertures extend through the base sheet and the top sheet.

3. The additive manufacturing system of claim **2**, wherein the top film comprises an adhesive tape.

4. The platen assembly of claim **1**, wherein the printing mechanism comprises one or more electrophotography engines and a transfer medium.

5. The additive manufacturing system of claim **1**, and further comprising at least one heating element configured to heat the platen plate and the magnetically coupled build sheet.

6. The additive manufacturing system of claim **1**, and further comprising a gantry mechanism operably secured to the platen plate.

7. The additive manufacturing system of claim **1**, wherein the one or more magnets are permanent magnets.

8. The additive manufacturing system of claim **1**, wherein the one or more magnets are electromagnets configured to receive electrical currents from the additive manufacturing system to generate and to disable the one or more magnetic fields.

9. A method for using a platen assembly in an electrophotography-based additive manufacturing system, the method comprising:

placing a first build sheet onto a top surface of a platen plate that is operably mounted to a gantry mechanism

of the additive manufacturing system by positioning a plurality of holes in the first build sheet about a plurality of members extending from the platen plate; magnetically coupling the placed first build sheet to the top surface of the platen plate;

printing imaged layers of a three dimensional part of charged powder material to a moving belt;

transferring the imaged layers of a three-dimensional part onto the magnetically-coupled first build sheet wherein the platen plate and build sheet moves in a synchronized rate of speed with the layer on the moving belt while heating and pressing the printed layers to previously printed layers over time: removing the first build sheet with the printed three-dimensional part from the top surface of the platen plate;

flexing the first build sheet to delaminate the three-dimensional part from the first build sheet; and

placing a second build sheet onto the top surface of the platen plate;

magnetically coupling the placed second build sheet to the top surface of the platen plate; and

printing layers of a second three-dimensional part onto the magnetically-coupled second build sheet.

10. The method of claim **9**, wherein the first build sheet comprises a ferromagnetic base sheet and a top film disposed on the ferromagnetic base sheet, and wherein printing layers of the three-dimensional part onto the magnetically-coupled first build sheet comprises printing layers of the three-dimensional part onto the top film of the first build sheet.

11. The method of claim **9**, wherein printing the layers of the three-dimensional part and printing the layers of the second three-dimensional part are each performed with an electrophotography-based additive manufacturing technique.

12. The method of claim **9**, wherein printing layers of the three-dimensional part onto the magnetically-coupled first build sheet comprises rolling a nip roller across the magnetically-coupled first build sheet.

13. The method of claim **9**, and further comprising heating the platen plate and the build sheet.

14. The method of claim **13**, and further comprising thermally insulating the platen plate from the gantry mechanism.

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