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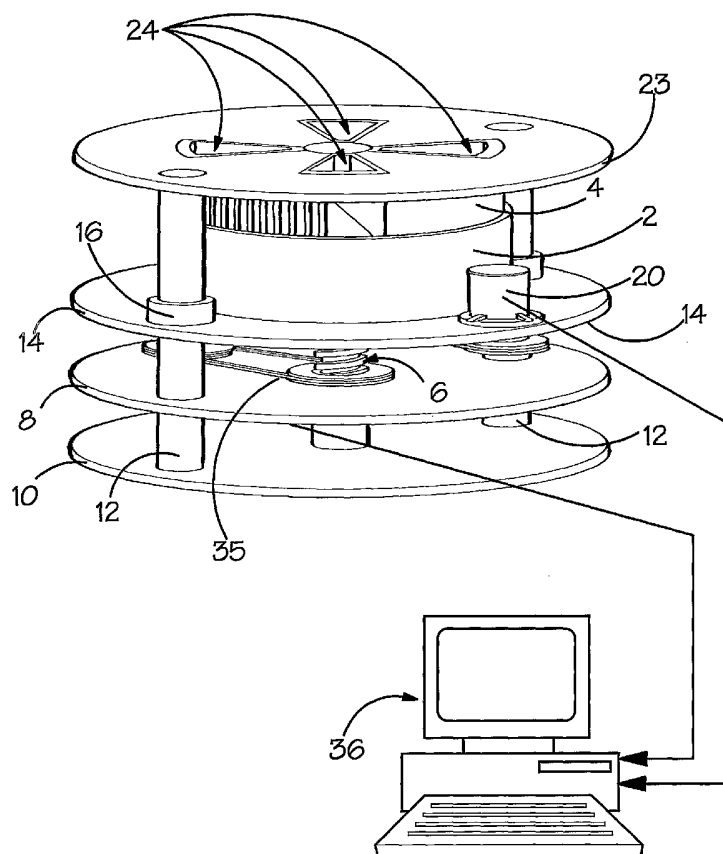
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[Continued on next page]

(54) Title: APPARATUS FOR MANUFACTURING THREE DIMENSIONAL ITEMS



(57) Abstract: An apparatus is disclosed for layer-on-layer manufacture of shaped three dimensional items. The process is controlled by a computer (36). The item is supported upon a build platform (2) and the apparatus additionally includes at least one build station (4) which serves to form upon the item under manufacture a layer of material having a controlled depth, and a shape determined by the computer controller. The build station and/or the build platform is/are mounted and driven to rotate about an axis. In this way the surface of the item under manufacture is repeatedly presented to the build station. The item is thereby built up from multiple layers of material. The rotational motion is advantageous in comparison with the reciprocal relative motion of existing "rapid prototyping" machines.



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DESCRIPTION

APPARATUS FOR MANUFACTURING THREE DIMENSIONAL ITEMS

The present invention relates to an apparatus for manufacturing three dimensional items from multiple layers of material.

A group of manufacturing techniques has been developed in recent years which are collectively referred to as "rapid prototyping" techniques. The same processes are sometimes known as "freeform fabrication" or "layer manufacturing". They allow complex three dimensional items to be automatically fabricated based on a computer representation of the item. The item is built up from a succession of thin layers of material which are formed under computer control and disposed one upon the other. The computer representation of the item can for example be generated using a CAD (computer aided design) package. The computer analyses the representation to produce what is in effect a contour map of the item. That is, the computer calculates the sectional shape, or contour, of the item in a series of parallel but separate planes. The rapid prototyping machine then forms, one upon another, layers of a build material having the required thickness (equal to the notional separation of the planes in the computer analysis) and also the required shape. In this way an item having the required shape is built up.

In the majority of existing rapid prototyping machines formation of each shaped layer involves:-

(1) forming upon the item under manufacture a layer of build material of controlled depth. The build material is typically in liquid or powder form at this stage and may for example be applied from a reservoir or hopper, with layer depth being regulated by a doctor blade or roller moved across the layer surface.

(2) applying a phase change method ("PCM") to solidify or fuse the material in selected regions to produce the required shape.

Such techniques include :-

(a) *stereolithography*, in which the item is built up in a bath of photosensitive polymer or resin which can be solidified by means of a light source, which may be a laser or digital light projection system. A build platform within the bath supports the item under manufacture. The laser scans a layer of liquid above the item to selectively solidify it. The platform is then moved downwards in the bath and the scanning process repeated.

(b) *powder binding*, in which a layer of material is spread from a hopper and a binder solution is "printed" (deposited) from a scanning head onto the powder material to cause the powder to cohere. The printing head used for this process can be very similar to the head of a conventional ink jet printer. Again the build platform is moved downwards between formation of successive layers to accommodate the increasing depth of the item. The printer head is moved across the item to enable the "scanning" necessary for printing. A similar technique is in use for manufacture of certain pharmaceutical tablets, the active ingredient, along with a binder, being

selectively printed onto a powder layer. Carefully controlled tablet characteristics, such as release rates, can be achieved.

c) *powder melting*, e.g. by selective application of laser light (“selective laser melting”). Metal powders have even been used in this type of process to form a solid metal part, a process referred to as *selective laser sintering*.

(d) *electron beam melting*, in which multiple electron beams selectively melt deposited powder to form solid material. The process is carried out under vacuum. In some instances the “build chamber” in which the process is carried out is heated.

There are also rapid prototyping techniques which do not involve formation of a uniform layer followed by a selective phase change. Instead the build material may be selectively deposited. In *wax extrusion*, wax micro droplets are fired from an ink jet style print head to “print” successive laminae making up the item. In *multi-jet modeling* a raster style print head ejects thermo-polymer material to build up the item. The above list of techniques is not exhaustive. All are familiar to those skilled in the art of rapid prototyping and are commercially available.

Rapid prototyping has been used, precisely as its name suggests, particularly for the fabrication of pre-production models, test items and so on. The current techniques are not well suited to production of items in larger volumes, particularly because they are slow. A single build process typically takes some hours due to the large number of layers which are required and the length of time required to form each layer. Rapid

prototyping techniques can be used in manufacture of tooling for more conventional, volume production, techniques such as injection moulding and casting.

However there is now a recognized commercial need to move from rapid prototyping to "rapid manufacture" in which the layer on layer approach used in rapid prototyping is applied to the manufacture of components in larger batch sizes. Such techniques offer the potential to fabricate components which cannot be made by moulding (there being no need to release the manufactured item from a mould, rapid manufacturing techniques are less limited in the range of shapes which can be manufactured than moulding) and whose shape can be modified without the need for replacement tooling. Rapid manufacturing is thus potentially an enormously flexible and useful technology. One goal of such technology is to provide so-called "mass customisation".

Cost and speed of manufacture currently limit the application of rapid manufacturing techniques to certain high margin, low volume fields including racing car components, custom hearing aids, dental aligners, spacecraft components and micro parts. As noted above, controlled release oral dosages of pharmaceuticals are also being prepared using techniques of the above described types. Increases in the speed of manufacture (the number of items manufactured per hour) are highly important in bringing rapid manufacture to a wider range of markets.

The devices used to deposit material and / or cause the selective phase change are normally reciprocally driven, moving back and forth across the item under manufacture. The present inventor has recognized that such techniques limit the speed of existing rapid prototyping and rapid manufacturing techniques.

In accordance with the present invention there is an apparatus for manufacturing three dimensional items, the apparatus comprising a computer controller, a build platform for carrying an item under manufacture, and at least one build station for forming upon the item a layer of material having a controlled depth and a shape determined by the computer controller, wherein either of the build station and the build platform is mounted and driven such as to rotate about an axis, thereby causing the build station and the item under manufacture to move past each other repeatedly, enabling the formation of successive layers to thereby manufacture an item having a chosen three dimensional shape.

The rotational motion of the build station relative to the build platform (which may result from rotation of one or the other, or could conceivably result from rotation of both) dispenses with the need for reciprocal motion of the build station.

Preferably the apparatus comprises two or more build stations circumferentially spaced about the rotational axis. This use of multiple build stations is made possible by the rotational movement of the build station relative to the build platform and makes it possible to form two or more layers in each rotation. As many layers are applied as there are build stations. Hence the present invention makes it possible to have multiple build stations operating concurrently and the build process is thus more rapid.

In order to accommodate the increasing depth of the item under manufacture resulting from formation of successive layers thereupon, either the build station or the build

platform is preferably moved along the rotational axis. Again, what is necessary is that the station and the platform should move relative to (away from) each other, but this can be achieved by moving one or the other, or conceivably both.

This movement along the rotational axis must be coordinated with the rotational movement. In a particularly preferred embodiment of the present invention this coordination is achieved using a screw threaded member, either of the build station and the build platform being rotatably engaged with the screw thread such as to be moved therealong by virtue of the rotational movement. The screw threaded member is preferably arranged to extend along the rotational axis.

The movement along the axis required upon a single rotation is typically small, since the depth of each layer of material is also small. Rather than use a screw thread of exceedingly fine pitch, in a preferred embodiment of the present invention the screw threaded member is itself rotatably mounted and driven to reduce the rate of the said movement along the rotational axis.

It has been conventional in rapid prototyping and manufacturing machines to keep the build platform - and so the item under manufacture - stationary and to move the build station. However in a preferred embodiment of the present invention it is the build platform which is rotated. A static build station may thus be used and this allows for improvements in build quality. In the case of powdered build material, finer powders may be used as a result.

A specific embodiment of the present invention will now be described, by way of example only, with reference to the accompanying drawings, in which:-

Figure 1 is a perspective illustration of a rapid manufacturing machine according to the present invention;

Figure 2 is similar to Figure 1 except that a mounting plate and associated build stations are omitted from the drawing to reveal other aspects of the machine's construction;

Figure 3 is a perspective illustration of one of the machine's build stations shown upright and viewed from one side;

Figure 4 is another perspective illustration of the build station, but viewed from beneath;

Figure 5 is a side elevation of the machine; and

Figure 6 is a further perspective illustration of the machine, a build chamber and mounting plate being omitted from this drawing.

Before considering the construction of the machine in detail, note that it comprises a build chamber 2, formed with a cylindrical wall and a flat planar base serving as a build platform, in which items are fabricated, the build chamber being rotatable to move the items repeatedly past build stations 4 by means of which the layers making up the item are deposited and selectively solidified. This particular machine is of the

“powder binding” type but it must be understood that the present invention is considered to be potentially applicable to most types of rapid prototyping/manufacturing techniques, including all of those referred to above. Note also that the build chamber 2 is coupled to a lead screw 6 and is thereby caused to move, as it rotates, along the direction of the screw axis (referred to herein as the “z axis”, which is also the axis about which the build chamber 2 rotates). This motion along the z axis allows the increasing depth of the items to be accommodated as successive layers are formed upon them.

Looking now at the detail of the machine's construction, upper and lower base plates 8, 10 are rigidly coupled to, and serve to support, two upstanding guide pillars 12, aligned parallel to the z axis, upon which slides a support plate 14. Sleeves 16 attached to the support plate run on the guide pillars and assist in ensuring that, while the support plate is able to slide along the guide pillars in order to move in the z direction, its position in the x and y directions, as well as its perpendicular orientation to the z axis, are fixed. The support plate 14 is circular and has a central, circular cut-out 16 which receives the build chamber 2, permitting the chamber to rotate about the z axis. In Figure 2 it can be seen that the build chamber 2 has a central boss 18 which embraces the lead screw 8. The boss is internally screw threaded so that as the build chamber rotates it is automatically moved along the z direction. The build chamber is provided with a rotational drive arrangement which in the illustrated embodiment comprises a chamber drive motor 20 acting through a belt drive indicated at 22.

Above the build chamber is a mounting plate 23 rigidly coupled to the guide pillars 12 which carries the build stations 4. Each build station forms a layer upon the item

being manufactured as it passes therebeneath. The build stations are separated from each other along the circumferential direction. In the illustrated embodiment there are four build stations. In a single revolution each item thus receives four layers of material. A single build station is illustrated in Figures 3 and 4, it comprises a hopper 24 which is upwardly open to receive the build material, which in this embodiment takes the form of a powder. The hopper 24 also has a downwardly open, constricted mouth 26 through which powder is dispersed. To control the depth of the resulting powder layer, a doctor blade is used, in the front of a straight edge 27 lying parallel to the bottom of the build chamber and adjacent the dispersing mouth 26. Because the item being manufactured moves along a circular path, the speed of movement of its surface past the hopper 24 is not the same over the entire surface but is instead proportional to distance from the axis of rotation. Consequently the rate of powder deposition required to achieve a uniform layer depth likewise increases with distance from the axis. To provide the required variation flow rate, the hopper 24 and mouth 26 broaden from their radially inner end 28 to their outer end 30. Selective phase change in the powder is achieved in this embodiment using a print head 32 of ink jet type which ejects a binder onto the items to define the shape of the built layer.

To keep the uppermost surface of the items under manufacture a consistent vertical distance from the build stations, it is necessary to advance the build chamber 2 (and the support plate 14 on which it is mounted) along the z axis by a distance equal to the layer thickness, each time the item passes a build station. A layer thickness of the order of 0.05mm. is typical in known rapid prototyping techniques. Hence in the illustrated embodiment the chamber would advance 0.05 mm. as it rotates through 90 degrees (to move from one of the build stations 4,6 to the next) and through 0.2 mm.

in a full rotation. If the lead screw 6 were fixed, this would necessitate use of a screw with a 0.2 mm. pitch. A screw with such a fine pitch is thought to be difficult to obtain.

In the illustrated embodiment the lead screw 6 is provided with its own drive comprising a screw drive motor 34 acting through a belt drive 35. The lead screw 6 is thereby driven to rotate in the same direction as the build chamber 2 but at a different speed, and the rate of advance of the build chamber is thus controlled by the difference in rotational speeds of the chamber 2 and screw 6. For example if the lead screw rotates at half the speed of the build chamber, then the chamber advances half the pitch of the screw thread in each rotation. The arrangement not only removes the need for an excessively fine pitched thread on the lead screw but also allows the rate of advance of the build chamber to be adjusted, by changing the speed of the lead screw 6 and/or chamber 2. The depth of each layer of build material may thereby likewise be varied. In the illustrated embodiment the two drive motors 20, 34 are electronically controlled allowing their relative speeds - and hence the layer depth - to be varied by the computer controller 36. An alternative (not illustrated) would be to link the build chamber and lead screw through a gear chain or other mechanical drive (such as a belt and pulley), in which case the layer depth would be controlled by the screw pitch and drive ratio.

The machine may operate continuously or intermittently. That is, the rotation of the build chamber may be continuous or may be periodically halted or slowed.

Continuous operation is faster since layering and phase change operations are carried out at the same time. However where the invention is implemented using certain

phase change methods, particularly laser-based methods, the phase change operation proceeds more slowly than the layer deposition. Intermittent operation, in which the rotation of the build chamber 2 stops or is slowed during phase change, permits the use of relatively slow phase change methods.

The computer controller 36 (Figure 1) is connected to the motors 20, 28 and also to the phase change stations and controls both.

In the above described embodiment the functions of build deposition and phase change are carried out by unitary build stations. However these two functions may be carried out by separate powder deposition and phase change stations, separated from each other along the circumferential direction. Also different build stations may be loaded with different build materials, enabling incorporation of two or more materials into the structure of the finished item.

It must be understood that the present invention is potentially applicable to any of the above described types of rapid prototyping and rapid manufacturing machines, and to other machines using the layer-on -layer fabrication technique.

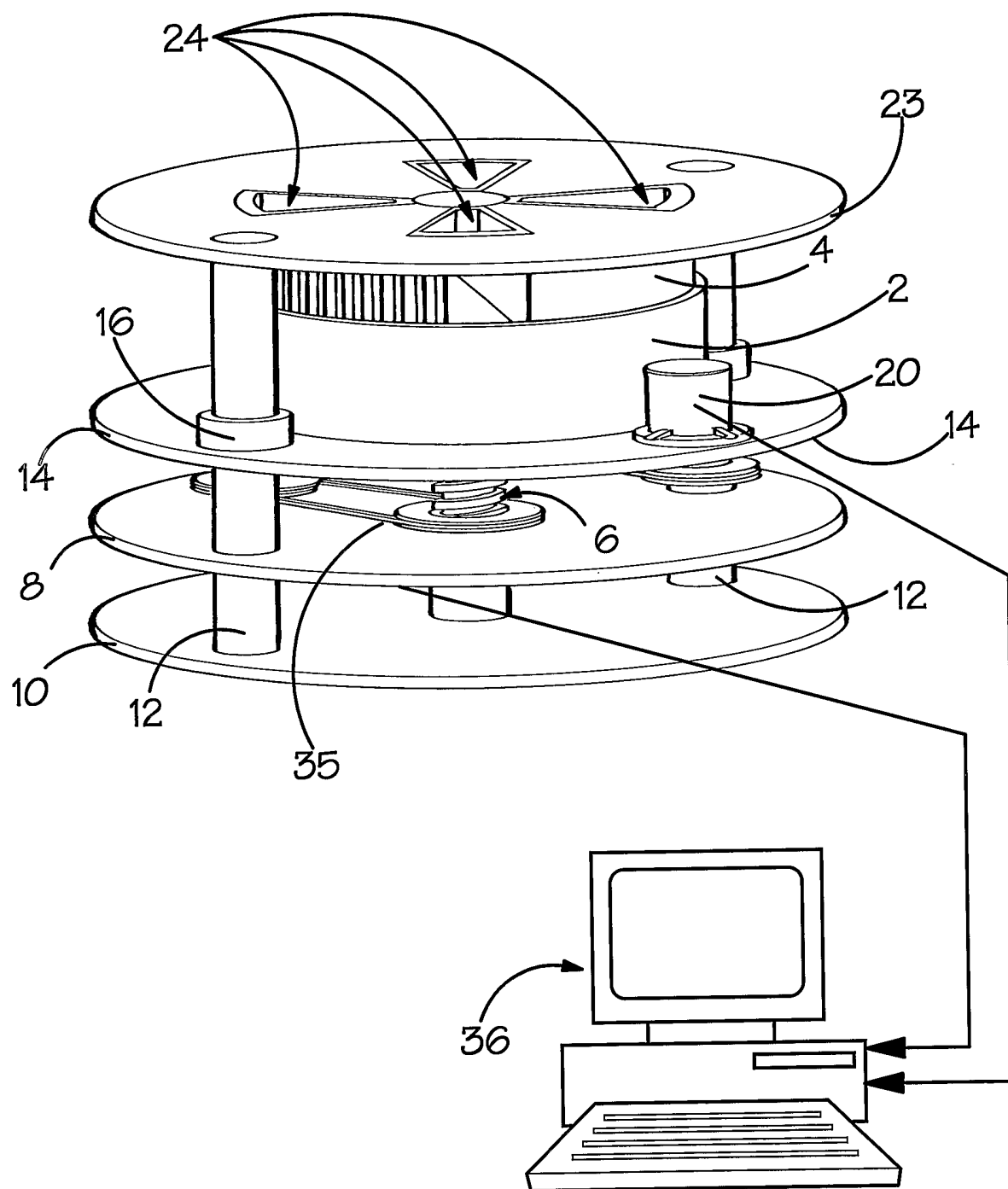
CLAIMS

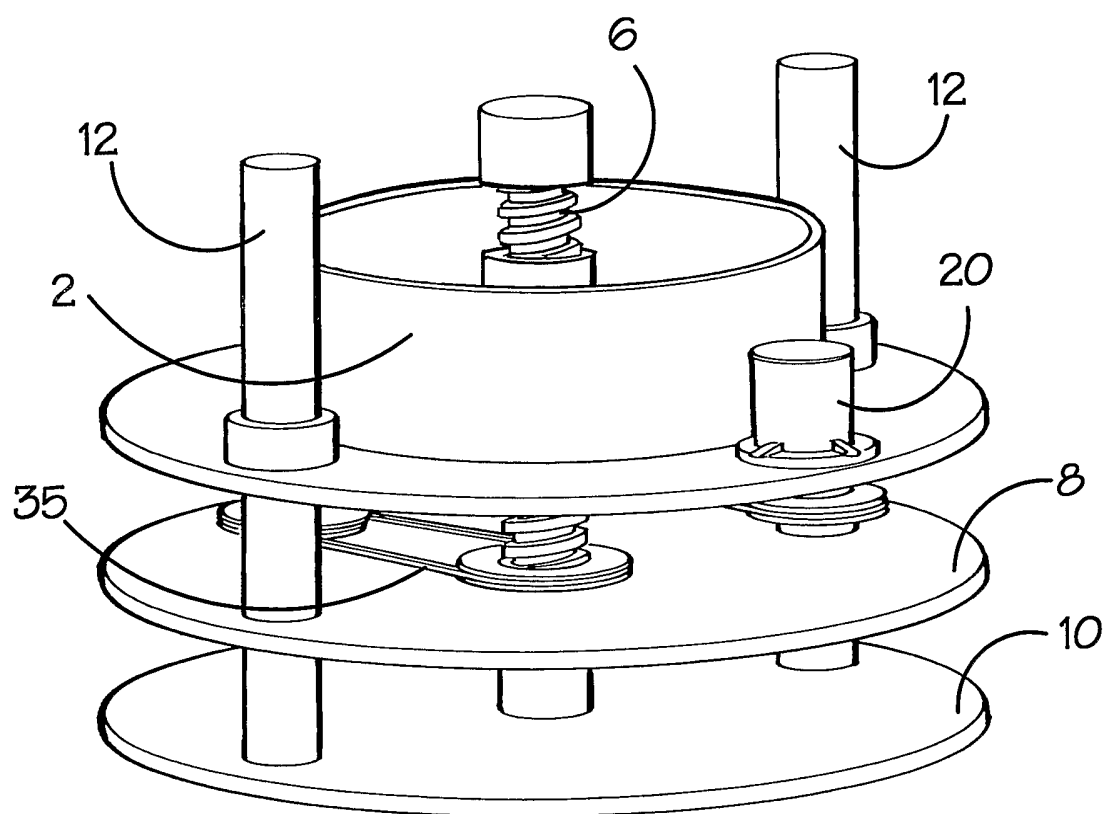
1. An apparatus for manufacturing three dimensional items, the apparatus comprising a computer controller, a build platform for carrying an item under manufacture, and at least one build station for forming upon the item a layer of material having a controlled depth and a shape determined by the computer controller, wherein either of the build station and the build platform is mounted and driven such as to rotate about an axis, so that the surface of the item under manufacture is repeatedly presented to the build station, enabling an item having a chosen three dimensional shape to be built up of multiple layers of material.
2. An apparatus as claimed in claim 1 wherein either of the build station and the build platform is moved along the rotational axis in order to accommodate the increase in depth of the item under manufacture resulting from formation of successive layers thereupon.
3. An apparatus as claimed in claim 2 further comprising a screw threaded member with which either of the build platform and the build station is rotatably engaged in order to produce the aforementioned movement along the rotational axis.
4. An apparatus as claimed in claim 3 wherein the screw threaded member extends along the rotational axis.

5. An apparatus as claimed in claim 3 or claim 4 wherein the screw threaded member is itself rotatably mounted and is driven such as to reduce the rate of said movement along the rotational axis.
6. An apparatus as claimed in any preceding claim wherein it is the build platform which is rotated.
7. An apparatus as claimed in claim 6 wherein it is the build platform which is moved along the axis of rotation.
8. An apparatus as claimed in claim 7 wherein the build platform is coupled to a support through a rotary bearing which provides for the build platform's rotational motion, the support being slidably mounted enabling the support and the build platform to move together along the rotational axis.
9. An apparatus as claimed in claim 8 wherein the support is slidably engaged with at least one pillar extending along the direction of the rotational axis.
10. An apparatus as claimed in any preceding claim comprising at least two build stations circumferentially spaced about the rotational axis so that in one rotation at least two layers are added to the item under manufacture.
11. An apparatus as claimed in any preceding claim wherein the or each build station comprises a deposition station for depositing a layer of build material and a phase

change station for selectively changing the phase of the layer of build material to form in it the shape determined by the computer controller.

12. An apparatus as claimed in claim 10 wherein the two build stations are loaded with different build materials.

**FIG.1.**

**FIG.2.**

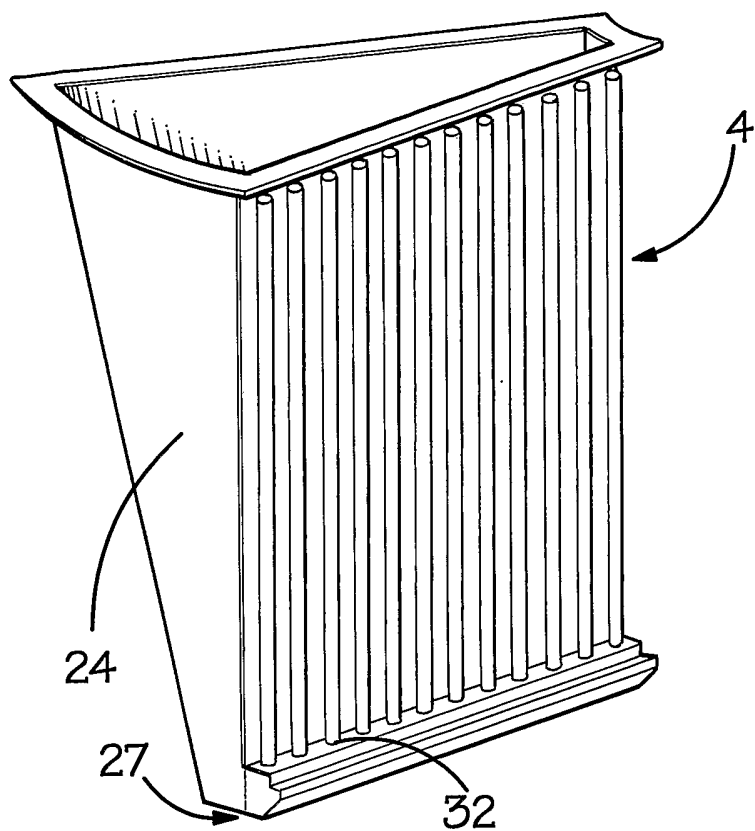


FIG.3.

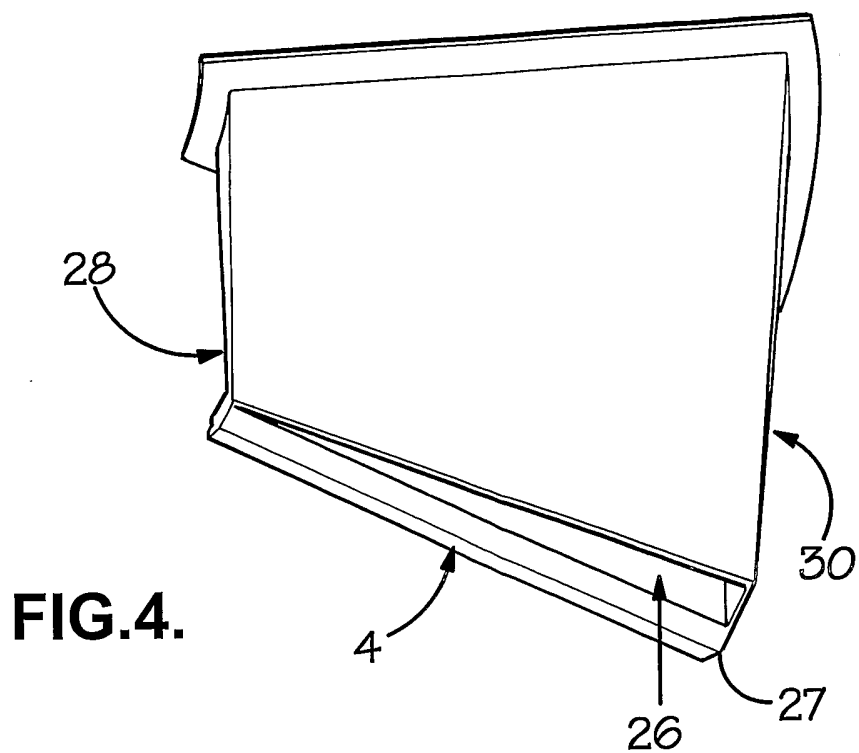


FIG.4.

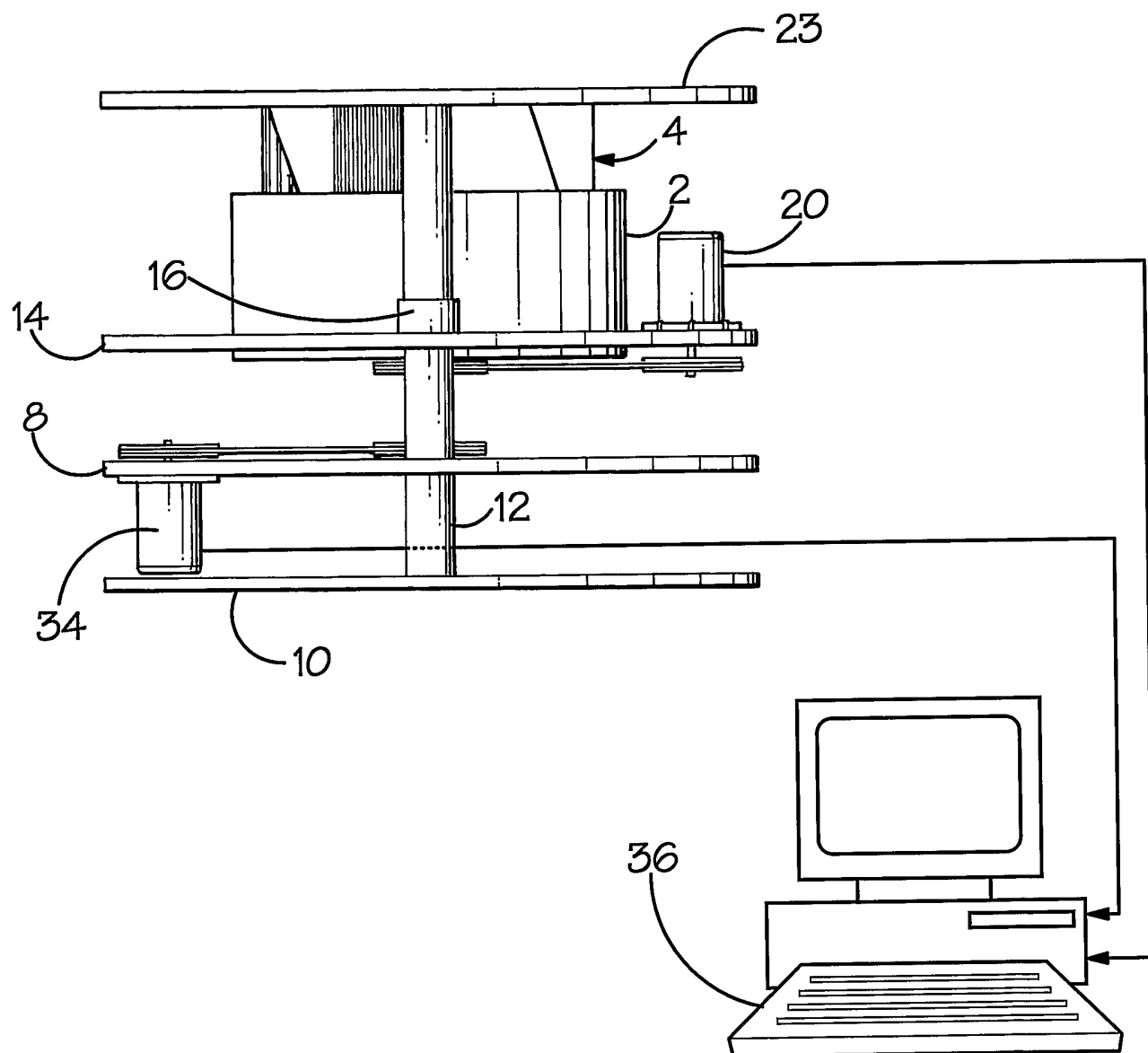
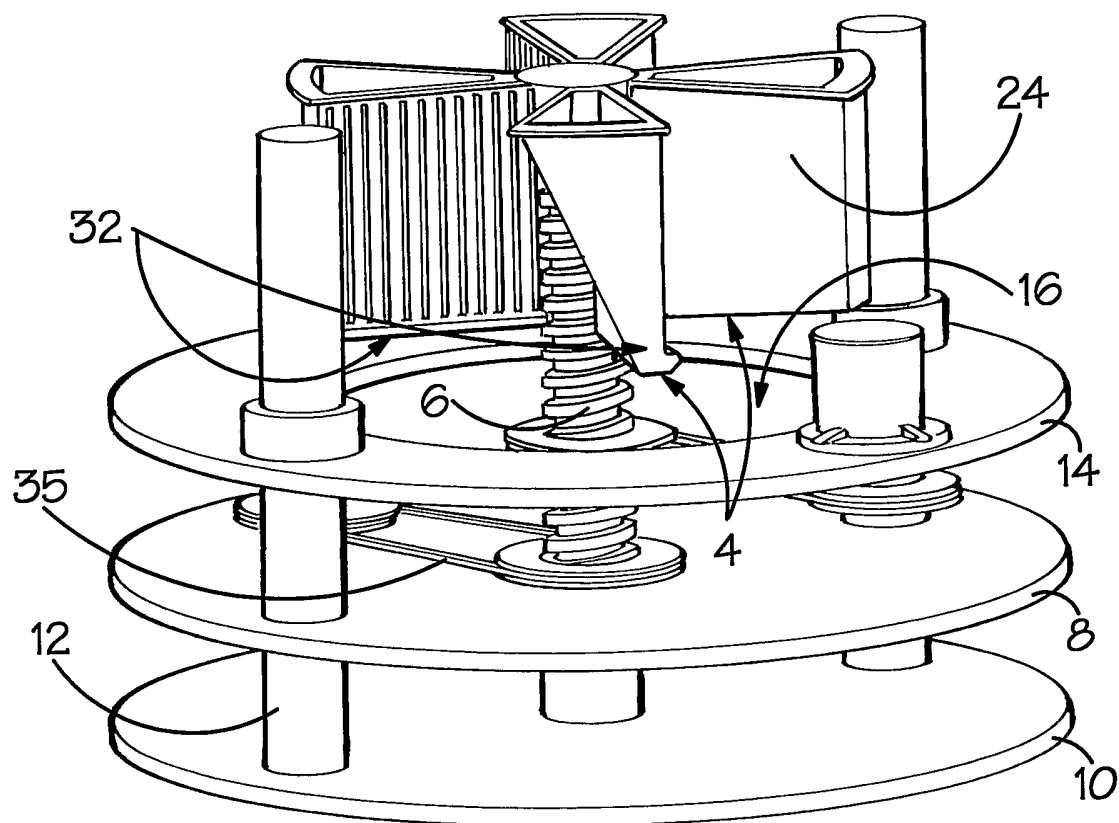


FIG.5.

**FIG.6.**

INTERNATIONAL SEARCH REPORT

International Application No
GB2004/002411

A. CLASSIFICATION OF SUBJECT MATTER

IPC 7 B29C67/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 7 B29C

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

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

EPO-Internal, PAJ, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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☐ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

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INTERNATIONAL SEARCH REPORT

information on patent family members

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