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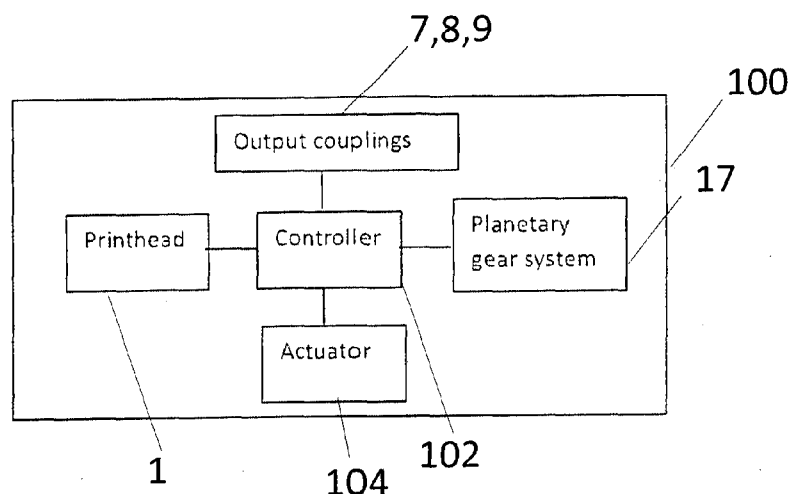
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(54) Title: A 3D PRINTER WITH A CONTROLLABLE ROTARY SURFACE AND METHOD FOR 3D PRINTING WITH CONTROLLABLE ROTARY SURFACE



(57) Abstract: There is provided a 3D printer with a controllable rotary surface. The 3D printer comprises at least one actuator; a planetary gear system configured to be engaged to the actuator; and a plurality of output couplings, each of the plurality of output couplings being configured to couple independently to at least one gear of the planetary gear system, and to engage independently with the controllable rotary surface. A method of 3D printing with a controllable rotary surface is also provided.

A 3D PRINTER WITH A CONTROLLABLE ROTARY SURFACE AND METHOD FOR 3D PRINTING WITH A CONTROLLABLE ROTARY SURFACE

FIELD OF INVENTION

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The present invention relates to a 3D printer and method for 3D printing with a controllable rotary surface.

BACKGROUND

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A three dimensional (3D) object can be fabricated by depositing a material onto a surface one layer at a time. Repetition of this process allows multi-laminated 3D objects to be fabricated. This is typically the process for 3D printing.

15 Currently, some prior art in relation to 3D printing are typically characterised by an X-Y-Z Cartesian coordinate system. It is usual for either the printbed (platform for receiving successive layers of a build material) or the printhead (the part that deposits the material onto the platform) to undergo movement in a rectilinear fashion. Specifically, the prior art are categorized into two types, namely, the gantry system and the moving bed system. In the gantry system, the printhead moves along the X and
20 Y axes, while the printbed moves only in the Z axis. In the moving bed system, movement along either the X or Y axes is carried out by the printbed. Unfortunately, the prior art is typically configured in a manner whereby the 3D printer has to occupy an area substantially larger than the printbed (typically more than 150% of the printbed area) in order to accommodate either the gantry, or the space required for movement of the printbed.

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In addition, other prior art in relation to 3D printing are typically characterized by a polar coordinate system. In such systems, the printbed is rotatable and the printhead is typically moving above the printbed in a radial fashion. Unfortunately, printing resolution for such systems deteriorates in a radial fashion, because given a constant polar angle, the longer the radius, the larger the distance between
30 points on the said radius.

Based on the aforementioned, it is evident that the prior art can be improved to result in a more space efficient 3D printer and which is able to print in a 3D manner without deterioration of print resolution.

SUMMARY

In a first aspect, there is provided a 3D printer with a controllable rotary surface. The 3D printer comprises at least one actuator; a planetary gear system configured to be engaged to the actuator; and
5 a plurality of output couplings, each of the plurality of output couplings being configured to couple independently to at least one gear of the planetary gear system, and to engage independently with the controllable rotary surface.

It is preferable that the controllable rotary surface is configured to couple to each of the plurality of
10 output couplings. In addition, it is preferable that each of the plurality of output couplings is configured to magnetically couple independently to at least one gear of the planetary gear system. Preferably, operations of the actuator, the planetary gear system and the plurality of output couplings are controlled by a controller. The controller may be external to the printer.

It is advantageous that the controller determines an angular rotation of the controllable rotatory
15 surface, the angular rotation depending on at least one of: dimensions of an object to be printed, contours of the object and so forth. It is also advantageous that the each of the plurality of output couplings coupled independently to at least one gear of the planetary gear system enables a plurality of printing resolutions.

In a second aspect, there is provided a method for 3D printing on a controllable rotary surface. The
20 method includes powering an actuator, the actuator being engaged to a planetary gear system; and coupling one of a plurality of output couplings to at least one gear of the planetary gear system. The method further includes coupling the rotary surface to the one of a plurality of output couplings.

It is preferable that one of a plurality of output couplings is magnetically coupled to at least one gear of
25 the planetary gear system. Advantageously, the coupling of one of a plurality of output couplings to at least one gear of the planetary gear system enables a plurality of printing resolutions.

DESCRIPTION OF FIGURES

In order that the present invention may be fully understood and readily put into practical effect, there
30 shall now be described by way of non-limitative example only preferred embodiments of the present invention, the description being with reference to the accompanying illustrative figures.

FIG. 1A – B are perspective views of main components of various embodiments of an apparatus for 3D printing in accordance with the invention.

FIG. 2 is an exploded view of a build drum and a printbed depicted in FIG. 1.

5 FIG. 3 is a top view of a planetary gear system of the build drum depicted in FIG. 2.

FIG. 4 is a top view of the output couplings depicted in FIG. 2.

FIG. 5A – C show angular resolution on the printbed depicted in FIG. 1 resulting from using a reduction ratio of 1:1, 2.6:1, and 3.6:1 respectively.

10 FIG. 6A – C show cross sectional views of corresponding states of the coupling system depicted in FIG. 4 when using a reduction ratio of 1:1, 3.6:1, and 2.6:1 respectively.

FIG. 7A – C show top views of the corresponding state of the gear reduction mechanism when using a reduction ratio of 1:1, 3.6:1, and 2.6:1 respectively.

FIG. 8 shows an example of a simplified gear transmission system.

FIG. 9 shows a schematic view of the apparatus for 3D printing in accordance with the invention.

15 FIG. 10 shows a process view of a method for 3D printing in accordance with the invention.

DESCRIPTION OF PREFERRED EMBODIMENTS

20 The preferred embodiments of the present invention provide a 3D printer which prints using polar coordinates. The 3D printer is configured to include logic for converting Cartesian coordinates to polar coordinates when printing is carried out, printing being with use of a rotatable surface. The 3D printer is also configured in a manner which is compact and does not take up a substantial amount of space. A corresponding method for 3D printing is also provided.

25 A three dimensional object can be fabricated by depositing a material over a flat surface one layer at a time. A single layer comprises a plurality of points with polar coordinates. In some instances, printheads go to a point, ejecting material which comes into contact to a printbed while moving on to the next target point. In other instances, the printheads go from point to point without ejecting any material. Once a layer is deposited, a subsequent layer is deposited onto the previous layer. Repetition
30 of this process allows multi-laminated three dimensional objects to be fabricated.

Referring to FIG. 1A, there is shown a perspective view of main components of a first embodiment of an apparatus for 3D printing 100. The apparatus 100 includes a printhead 1 and a printbed 2. The printhead 1 is configured to be movable in a radial manner relative to a centre of the printbed 2 (along

radial axis 3) and linearly in the Z-axis 4 (along a vertical track 6). The printbed 2 is configured to be rotatable around an axis that is situated at or around the centre of the printbed 2. The printhead 1 is of an extruder-type and is capable of ejecting semi-solid material, such as, for example, polylactic acid, acrylonitrile butadiene styrene, nylon, polyvinyl alcohol, and so forth. The semi-solid material can be solidified either over time or using externally stimulated chemical reactions. While the printbed 2 is rotating, the semi-solid material can be deposited onto either the printbed 2 or a prior deposited layer material. The apparatus 100 also includes a build drum 5, the build drum 5 being configured to rotate the printbed 2. Further details of the build drum 5 will be provided in a subsequent portion of the description.

Referring to FIG.1B, there is shown a perspective view of main components of a second embodiment of the apparatus for 3D printing 200. The apparatus 200 includes a plurality of printheads 1' and a printbed 2'. Similar to the first embodiment, each printhead 1' is configured to be movable in a radial manner relative to a centre of the printbed 2' and linearly in the Z-axis (along a vertical track 6'). Each printhead 1' is configured to deposit material in a similar manner as described earlier. In the second embodiment, simultaneous independent control of the plurality of printheads 1' enables both high throughput 3D printing and 3D printing of using a second material(s)/additive(s) to a first material. The apparatus 200 also includes a build drum 5', the build drum 5' being configured to rotate the printbed 2'. The build drum 5' is substantially similar to the build drum 5.

FIG. 2 shows an exploded view of the build drum 5 of the apparatus 100 shown in FIG. 1A. The printbed 2 is configured to rest on the build drum 5. The build drum 5 includes a plurality of output couplings, namely, a first output coupling 7, a second output coupling 8, and a third output coupling 9. A top view of the output couplings 7, 8, 9 is also showed in FIG. 4. The build drum 5 further includes a planetary gear system 17, the gear system 17 including a plurality of planetary gears 15, a sun gear 14 and a ring gear 16. A top view of the planetary gear system 17 is shown in FIG. 3. The first output coupling 7 is able to couple to the sun gear 14. The second output coupling 8 is able to couple to the plurality of planetary gears 15. The third output coupling 9 is able to couple to the ring gear 16. Each gear 14, 15, 16 is able to couple to a respective output coupling 7, 8, 9 through use of magnetic attraction. This is enabled by locating an array of alternating pole permanent magnets on either the gear 14, 15, 16 or the output coupling 7, 8, 9, with electrically conductive materials being located at respective mating parts. For example, if the array of alternating pole permanent magnets is located at the gear 14, 15, 16, whenever the gear 14, 15, 16 undergoes translation (movement), an electric current is induced in the conductive material which results in a magnetic field that attracts the array of alternating pole

permanent magnets and enables coupling of the moving gear and corresponding output coupling. Each respective gear and output coupling pair is configured to rotate at the same rate.

In the planetary gear system 17, one of the three types of gears 14, 15, 16 that is clutched to an actuator drives the other gears, one of which will act as an output and is clutched to the printbed 2 via one of the output couplings 7, 8, 9. By choosing different clutch combinations of gear types as input and output, a number of reduction ratios can be made available to provide different printing resolutions. This can be carried out by clutching one of the output couplings 7, 8, 9 to the printbed 2, while maintaining other couplings in a stationary state in the build drum 5. The capability to increase the reduction ratio by varying clutching of output couplings is able to compensate for deterioration of printing resolution as the radius of printing increases. The main function of the planetary gear system 17 is to reduce the minimum angular rotation on the printbed 2 relative to actual actuation. The planetary gear system 17 also affects changes in the torque and speed of the resulting rotation of the printbed 2.

Using the first embodiment of the apparatus 100 as an example, when a target point is provided, the printhead 1 is brought to desired radial and Z positions, corresponding respectively to a radial factor in the polar coordinate system and the height of the point in three dimensional space. In addition, the printbed 2 is rotated at an angle in the polar coordinate system which aligns the target point on the printbed 2 with the printhead 1.

In order to rotate the printbed 2, the actuator causes an angular rotation that is reduced by the planetary gear system 17, whereby the reduced angular rotation is equivalent to the angle of the target point in the polar coordinate system, with a desired input and output coupling determined by a converting logic. It should be appreciated that the converting logic typically either resides in a controller that controls the operation of the apparatus 100 or exists as software that can be run on a separate data processing apparatus. The converting logic can be an algorithm which converts parameters of the object to be printed into polar coordinates, the parameters being, for example, dimensions of the object, contours of the object, and so forth.

For the sake of illustration, FIG. 5A - C shows a series of print paths on the printbed 2 resulting from using a reduction ratio (for the planetary gear system 17) of 1:1, 2.6:1, and 3.6:1 respectively, assuming that the minimum angular rotation that can be actuated by the actuator is 5 degrees. It is evident from

FIG. 5A – C that various printing resolutions can be achieved by manipulating the characteristics of the planetary gear system 17 (for example, in manipulating a number of teeth in each planetary gear 15).

FIG. 6A – C show cross-sectional views of corresponding states of the respective output couplings from use of reduction ratios of 1:1, 3.6:1, and 2.6:1 respectively. It will be evident from FIG. 6A – C that in order for the reduction ratios to be varied, one of the output couplings 7, 8, 9 corresponding to a desired reduction ratio will be clutched 11 (engaged) to the printbed 2 while the other output couplings remain disengaged 12 from the printbed 2. The clutching/engagement of the output couplings 7, 8, 9 and the printbed 2 can be using, for example, magnetic attraction, levers, cables, springs in combination with friction, meshing of structure between the two clutched surface, and so forth.

Referring to FIG. 7A – C which show the movement of the planetary gear system 17 corresponding to FIG. 6A – C, in some instances some of the output couplings not clutched to the printbed 2 will be held stationary 13, while in other instances, some of the output couplings will be held afloat by biased means, such as, for example springs. In all instances, one of the output couplings will be engaged to the actuator.

Referring to FIG. 6A and FIG. 7A, when the first output coupling 7 is engaged to the actuator and also chosen as the output that is clutched 11 to the printbed 2, it does not matter if the rest of the output couplings are held fixed to the apparatus or held afloat. This gives a reduction ratio of 1:1 as shown in FIG. 5A.

Referring to FIG. 6B and FIG. 7B, when the first output coupling 7 is engaged to the actuator, and the second output coupling 8 is chosen as the output that is clutched 11 to the printbed 2, third output coupling 9 will be held stationary 13. This gives a reduction ratio of 3.6:1 as shown in FIG. 5C.

Referring to FIG. 6C and FIG. 7C, when the first output coupling 7 is engaged to the actuator, and the third output coupling 9 is chosen as the output that is clutched 11 to the printbed 2, the second output coupling 8 will be held stationary 13. In order for coupling 9 to rotate, ring gear 16, planetary gears 15 and the sun gear 14 all have to rotate. This gives a reduction ratio of 2.6:1 as shown in FIG. 5B in the opposing rotational direction.

Referring the FIG. 8, there is shown a gear system in the build drum 5 that provides only a single reduction ratio. Such a gear system comprises an offset spur gear 402 mated with an internal gear 400. In this arrangement, the spur gear 402 can be clutched or permanently engaged to the actuator to drive the internal gear 400 which rotates at a reduced minimum angular rotation relative to the spur gear 402. The internal gear 400 can be clutched or permanently engaged to the printbed 2.

The aforementioned apparatus 100, 200 include methodology both for calculating an angular rotation needed to be actuated by the actuator, and for determining the choice of output couplings to be clutched to the printbed 2, 2' and the ones that are to be stationary. It should be appreciated that the converting logic typically either resides in a controller that controls the operation of the apparatus 100, 200 or exists as software that can be run on a separate data processing apparatus.

Referring to FIG. 9, there is shown a schematic diagram of the main components of the apparatus for 3D printing 100. The apparatus 100 includes the controller 102, which controls the printhead 1, the planetary gear system 17 (that is, which gears are engaged or not), the output couplings 7, 8, 9 (that is, which output couplings to hold stationary, and those to move) and operation of the actuator 104. It should be appreciated that the controller 102 can also reside outside the apparatus 100. It is evident that the controller 102 controls the reduction of angular rotation of the printbed 2.

It should be appreciated that the apparatus 100, 200 are in a configuration which is compact and does not take up a substantial amount of space. This is advantageous as the apparatus 100, 200 can be used in homes and areas where there are space constraints.

FIG. 10 shows another aspect of the invention, a process flow of a method for 3D printing on a controllable rotary surface (300). The method 300 re-iterates the processes carried out by the apparatus 100, 200 when carrying out 3D printing with a plurality of printing resolutions.

To further clarify the processes described earlier, the method 300 includes powering the actuator 104, with the actuator 104 being engaged to the planetary gear system 17 (302). Subsequently, there is coupling of one of a plurality of output couplings 7, 8, 9 to at least one gear of the planetary gear system 17 (304). The planetary gear system 17 includes a sun gear 14, a plurality of planetary gears 15, and a ring gear 16. Next, there is coupling of the printbed 2 to the one of a plurality of output couplings 7, 8, 9 (306). This is also shown in FIG. 6, whereby the coupling is enabled by magnetic attraction. It

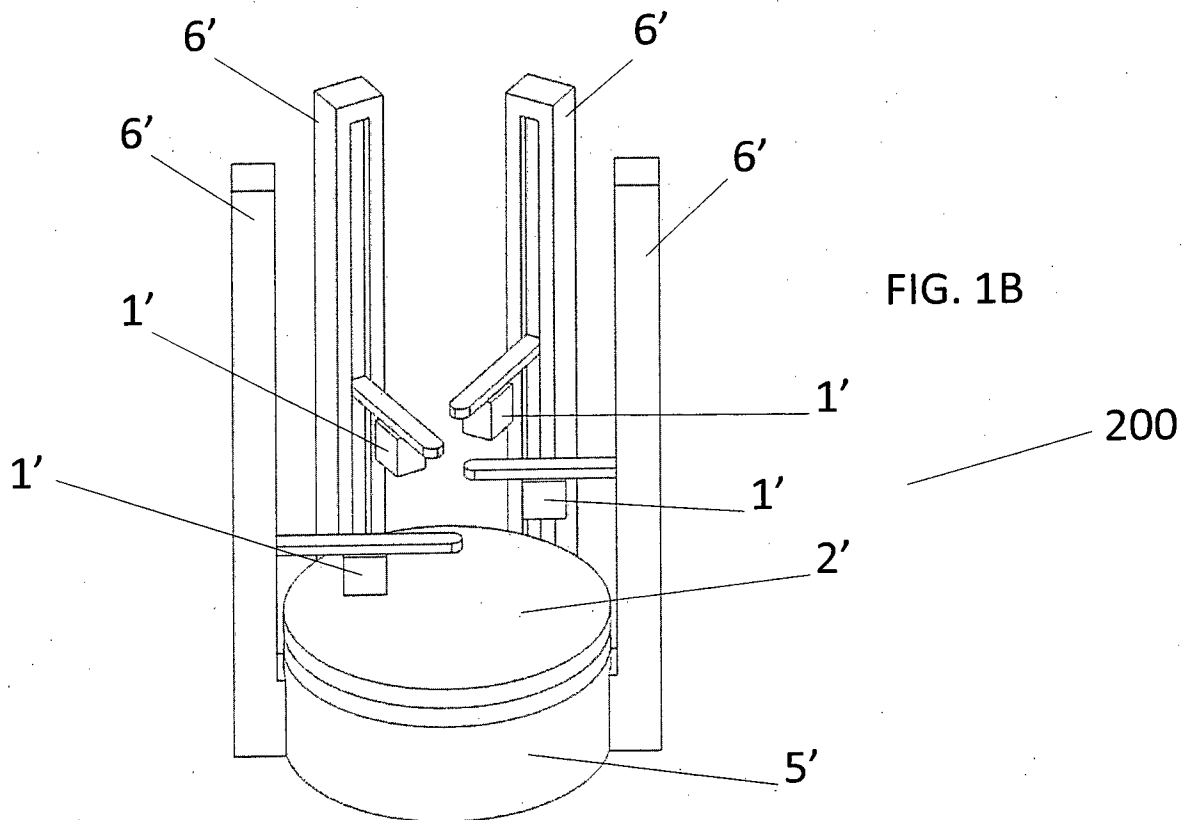
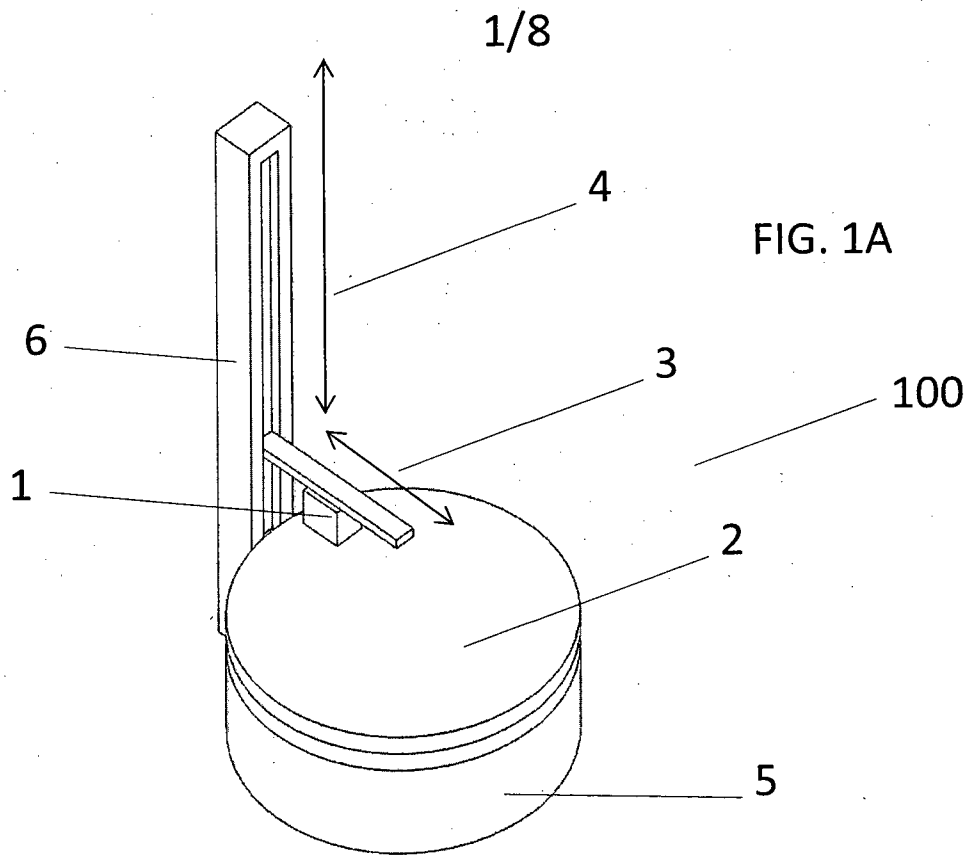
should be appreciated that the method 300 can also be carried out using a 3D printer which is not integrated with a rotary printbed 2.

Whilst there have been described in the foregoing description preferred embodiments of the present invention, it will be understood by those skilled in the technology concerned that many variations or modifications in details of design or construction may be made without departing from the present invention.

CLAIMS

1. A 3D printer with a controllable rotary surface comprising:
at least one actuator;
5 a planetary gear system configured to be engaged to the actuator; and
a plurality of output couplings, each of the plurality of output couplings being configured to
couple independently to at least one gear of the planetary gear system, and to engage independently
with the controllable rotary surface.
- 10 2. The printer of claim 1, wherein the controllable rotary surface is configured to couple to each
of the plurality of output couplings.
3. The printer of either claims 1 or 2, wherein each of the plurality of output couplings is
configured to magnetically couple independently to at least one gear of the planetary gear system.
- 15 4. The printer of any one of claims 1 to 3, wherein operations of the actuator, the planetary gear
system and the plurality of output couplings are controlled by a controller.
5. The printer of claim 4, wherein the controller is external to the printer.
- 20 6. The printer of either claim 4 or 5, wherein the controller determines an angular rotation of the
controllable rotary surface, the angular rotation depending on at least one of: dimensions of an
object to be printed and contours of the object.
- 25 7. The printer of any one of claims 1 to 6, wherein the each of the plurality of output couplings
coupled independently to at least one gear of the planetary gear system enables a plurality of printing
resolutions.
8. A method for 3D printing on a controllable rotary surface, the method including:
30 powering an actuator, the actuator being engaged to a planetary gear system; and
coupling one of a plurality of output couplings to at least one gear of the planetary gear system.
9. The method of claim 8, wherein one of a plurality of output couplings is magnetically coupled
to at least one gear of the planetary gear system.

10. The method of either claim 8 or 9, wherein the coupling of one of a plurality of output couplings to at least one gear of the planetary gear system enables a plurality of printing resolutions.
- 5 11. The method of any one of claims 8 to 10, further including coupling the rotary surface to the one of a plurality of output couplings.



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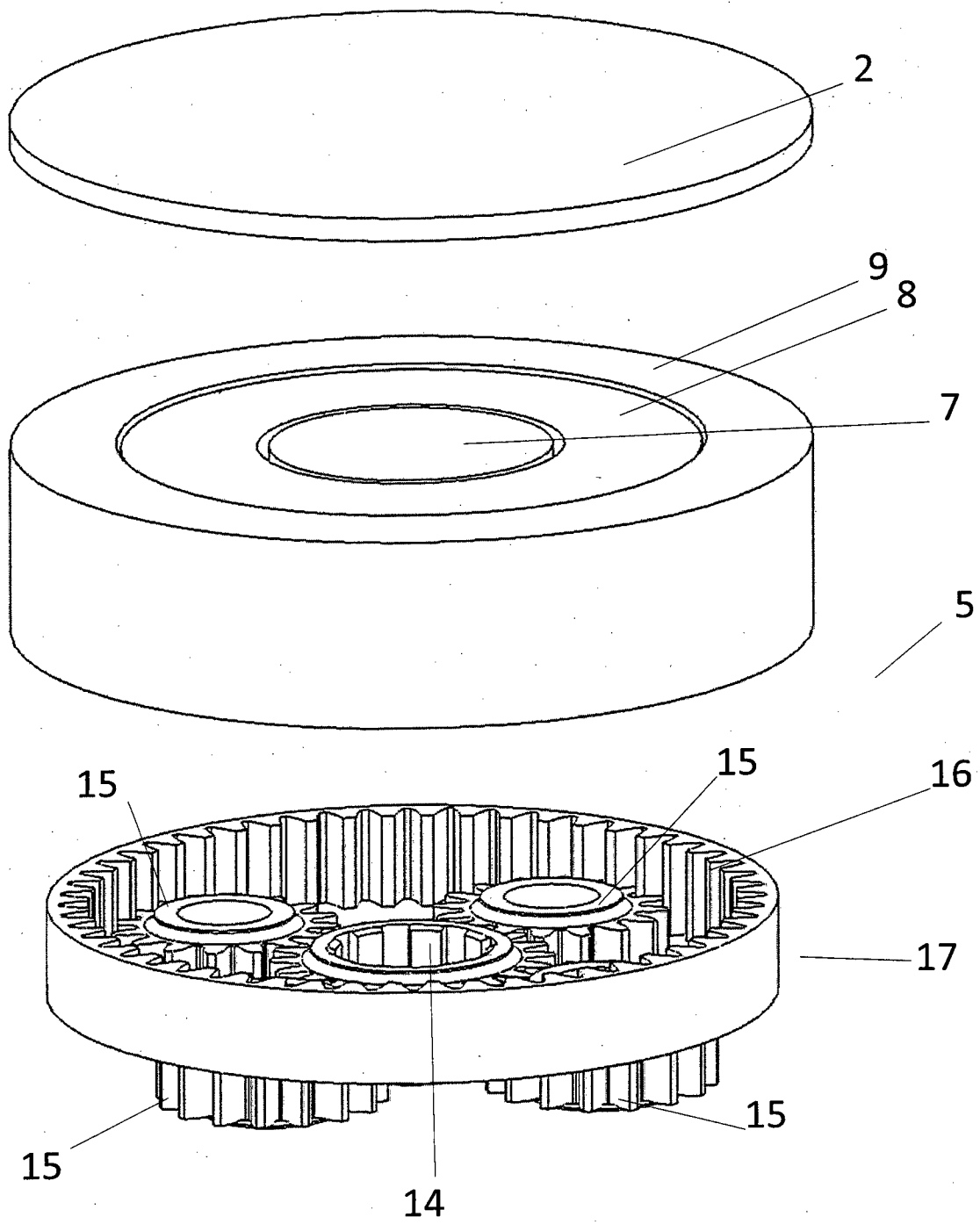
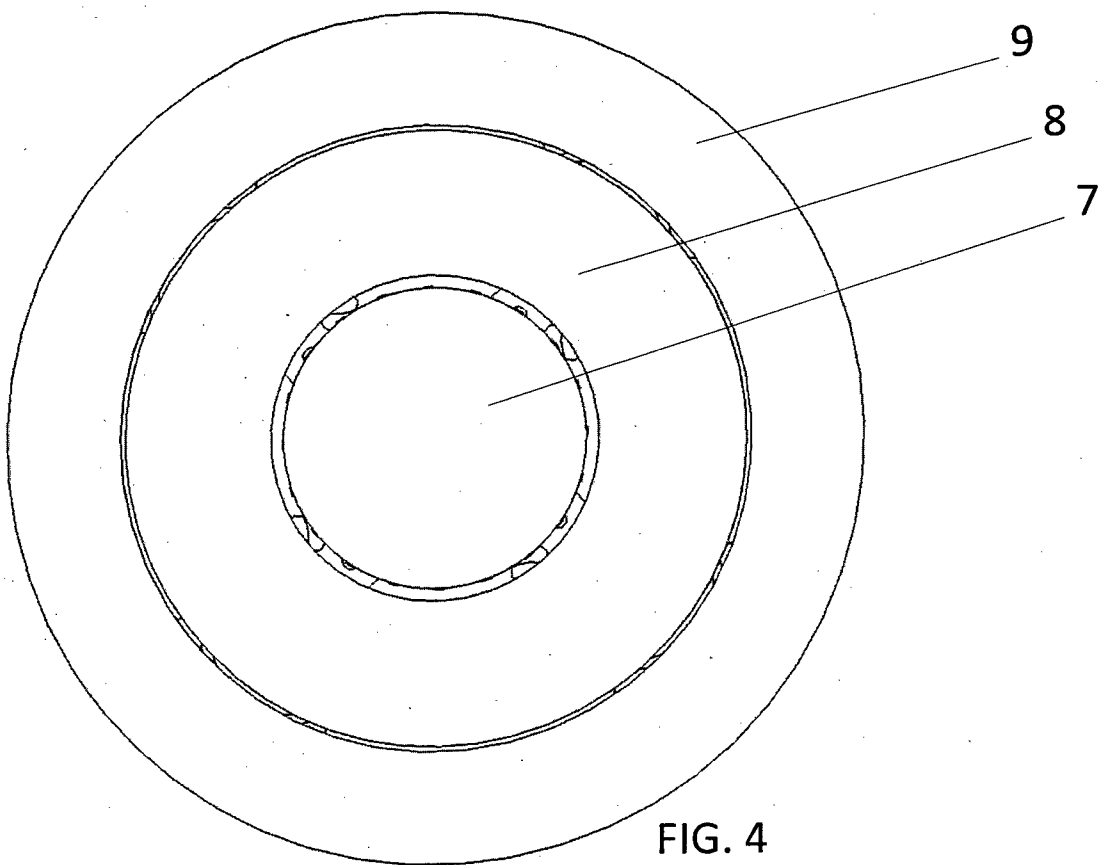
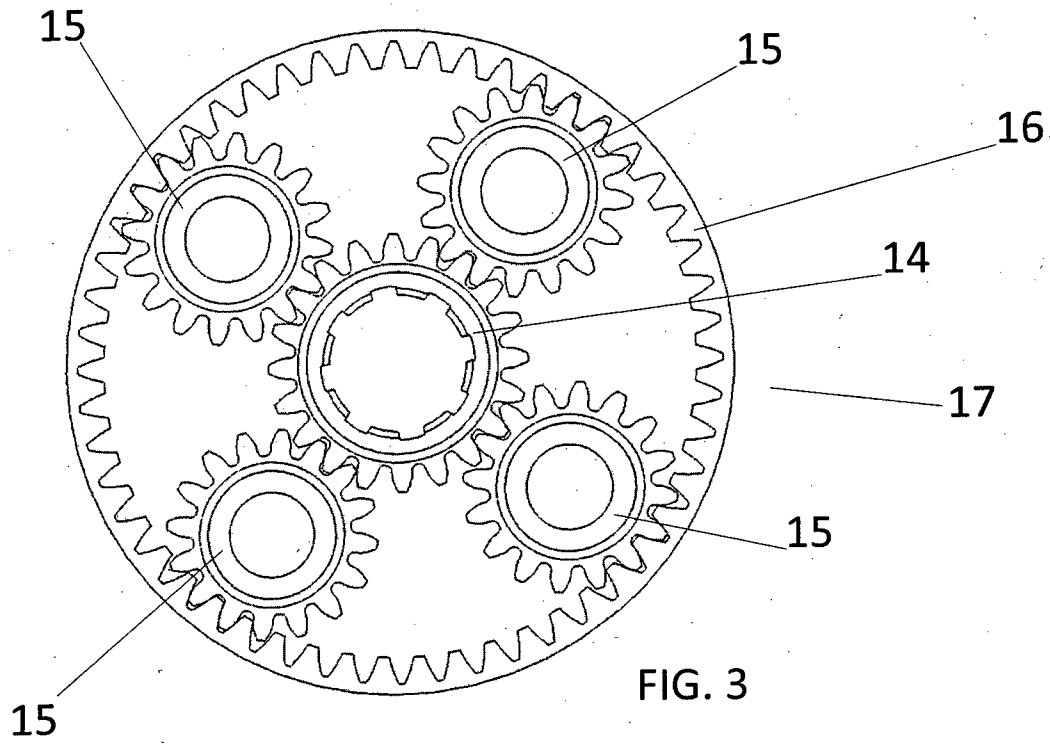


FIG. 2

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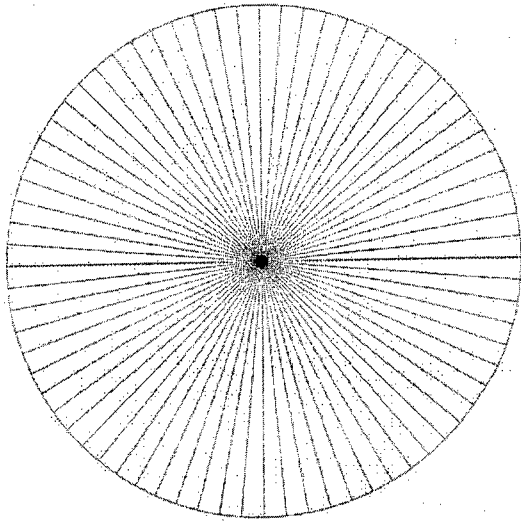


FIG. 5A

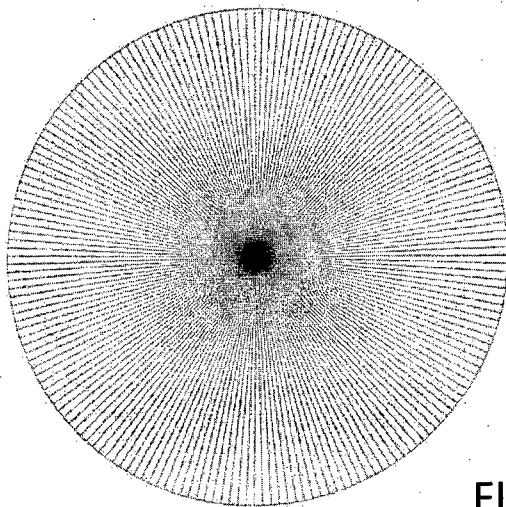


FIG. 5B

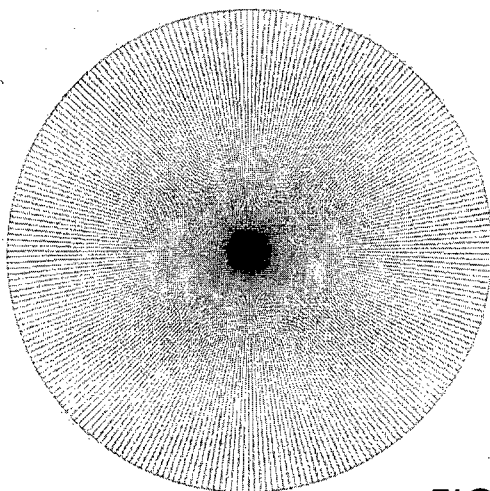
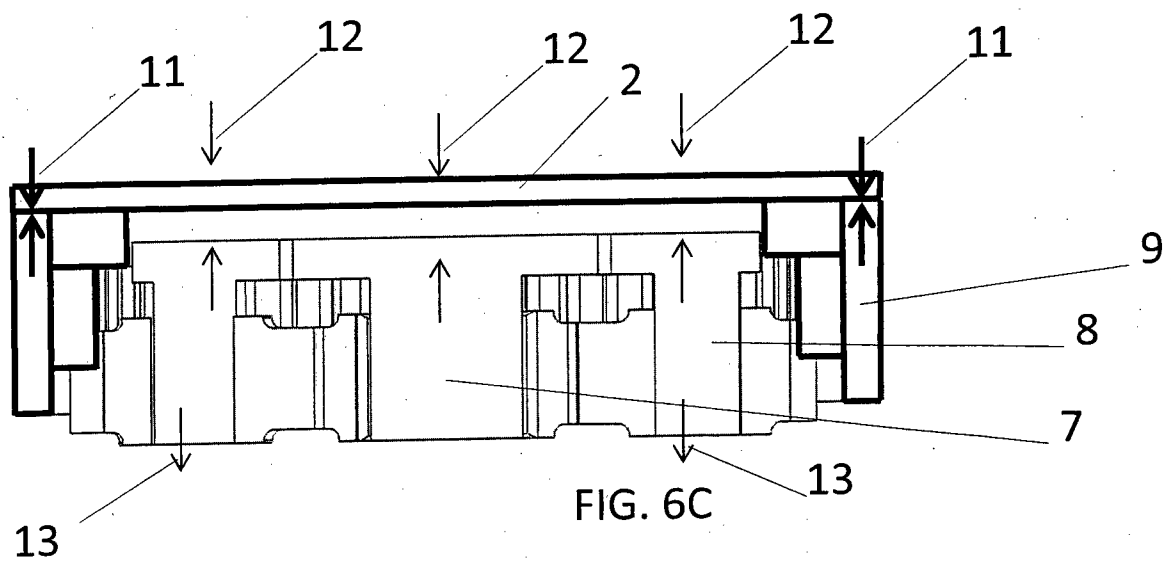
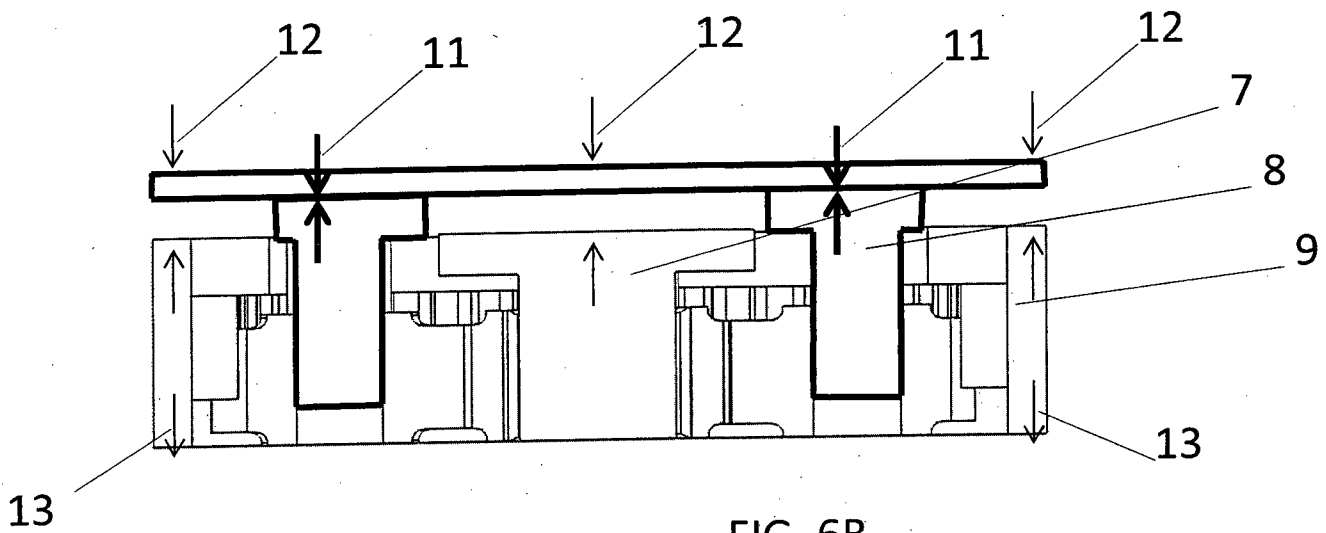
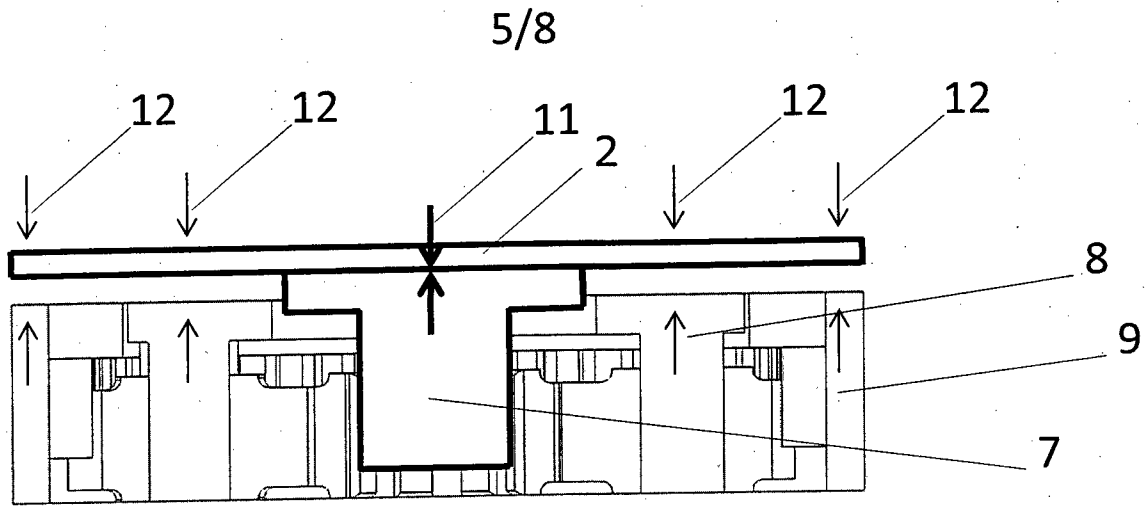
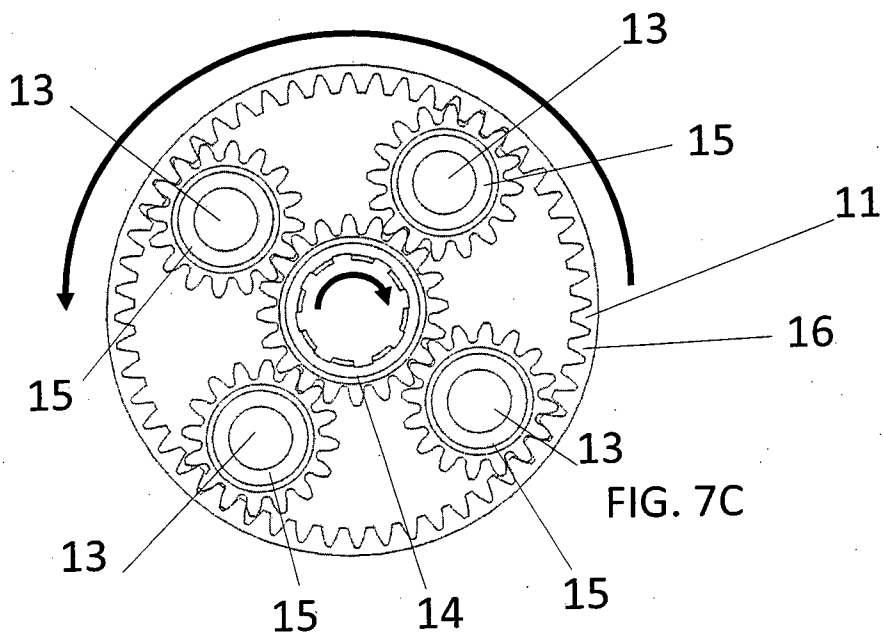
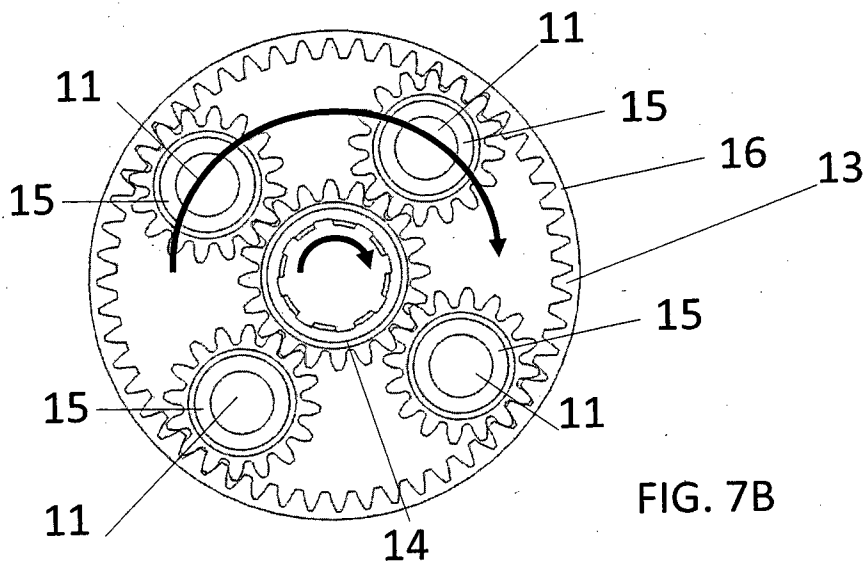
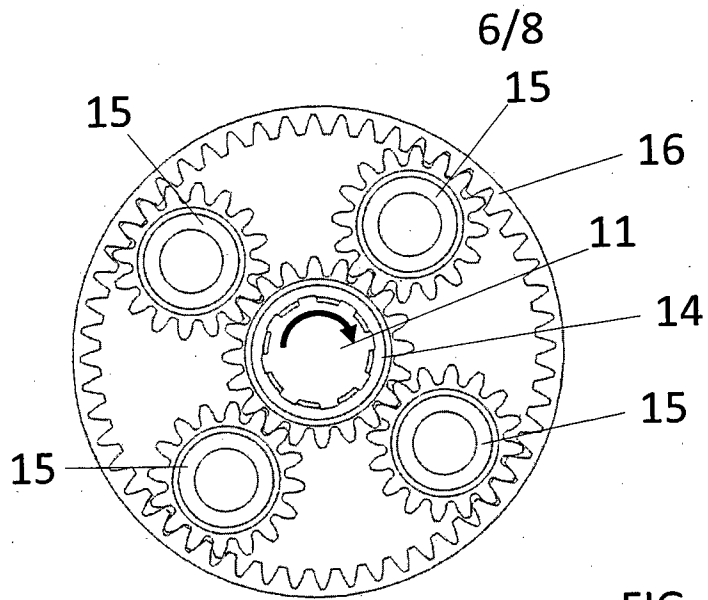


FIG. 5C





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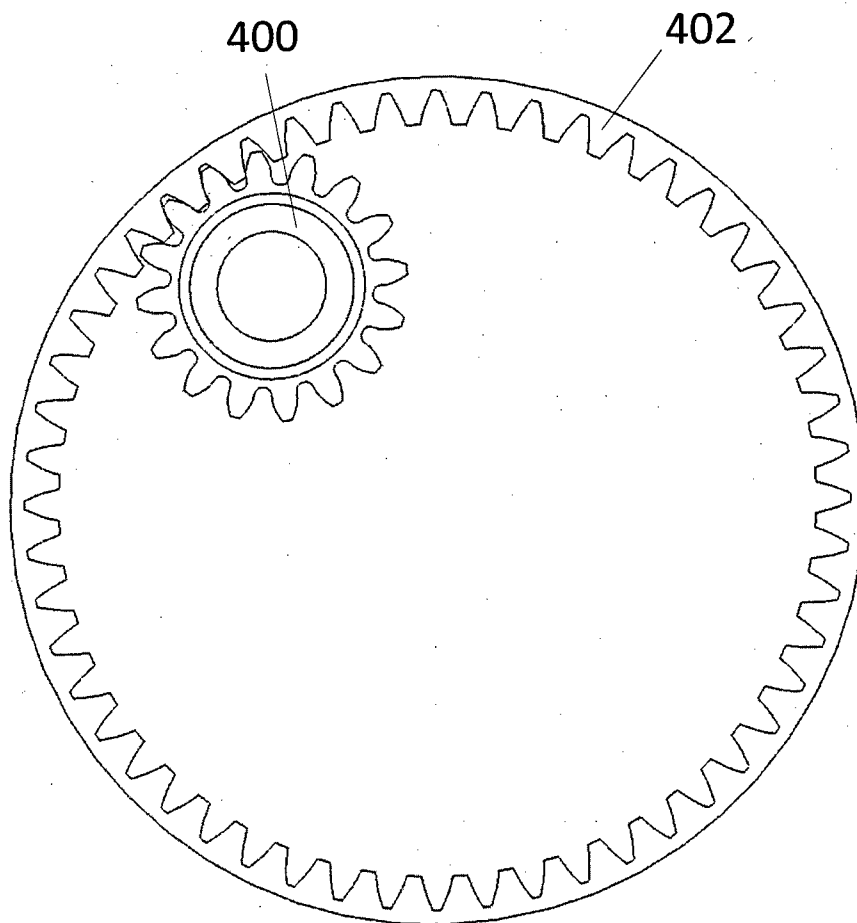


FIG. 8

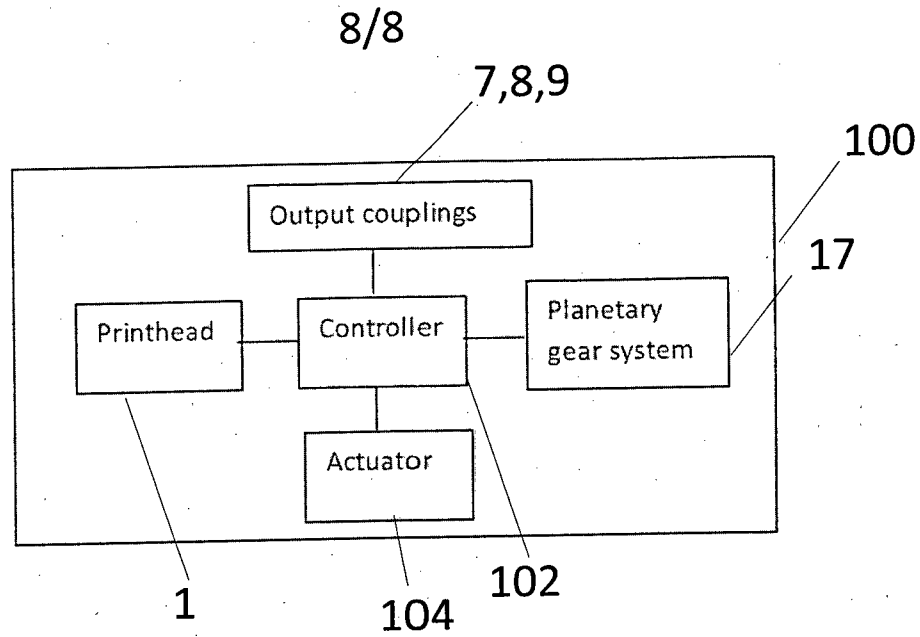


FIG. 9

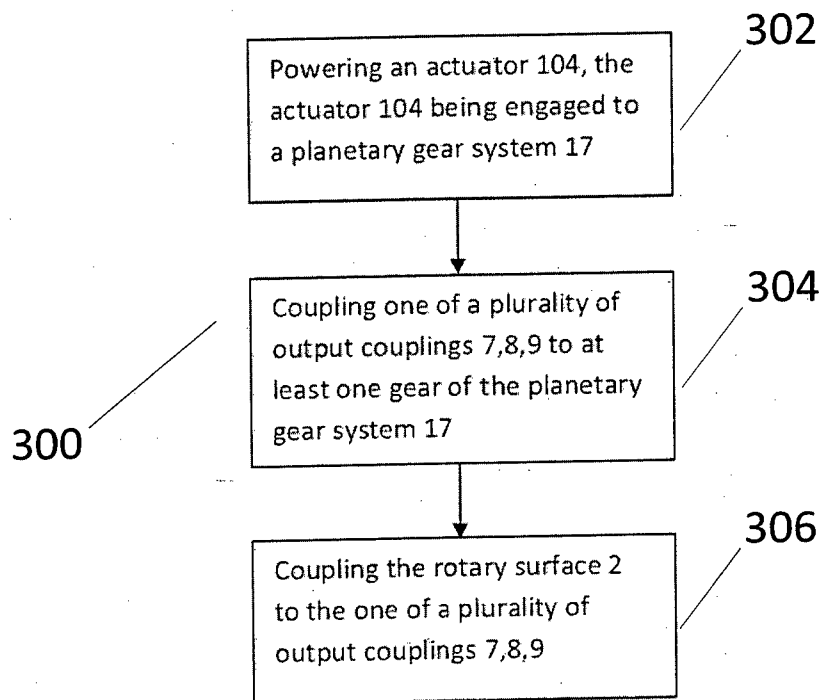


FIG. 10

INTERNATIONAL SEARCH REPORT

International application No.

PCT/SG2013/000529

A. CLASSIFICATION OF SUBJECT MATTER

B29C 67/00 (2006.01) F16H 48/11 (2012.01) B28B 1/14 (2006.01)

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)

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 practicable, search terms used)

WPI, EPODOC: IPC F16H48/11 & Keywords (planetary gear, epicyclic gear, 3D printer, additive manufacturing, rotate, angular, polar) & like terms; TXTUS5, TXTUS4, TXTUS3, TXTUS2, TXTUS1, TXTUS0, TXTEP1, TXTGB1, TXTWO1, TXTAU1, TXTCA1, TXTSG1: Keywords (planetary gear, epicyclic gear, 3D printer, additive manufacturing, rotate, angular, polar) & like terms; Google: Keywords ("planetary gear", "epicyclic gear", 3D, additive manufacturing, scanner, table, rotating, variable, gear) & like terms; Espacenet: Applicant: Blacksmith group; Inventor: Pui Tze Sian OR Kongsuphol OR Fang Kok

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
	Documents are listed in the continuation of Box C	

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* Special categories of cited documents:	
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Date of the actual completion of the international search 19 March 2014	Date of mailing of the international search report 19 March 2014
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INTERNATIONAL SEARCH REPORT		International application No.
C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		PCT/SG2013/000529
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2008/0042321 A1 (RUSSELL et al.) 21 February 2008 Abstract, FIG. 1-3, PARA [0048]	1-11
A	US 2001/0035886 A1 (BRADSHAW et al.) 01 November 2001 Abstract, FIG. 2	1-11

Form PCT/ISA/210 (fifth sheet) (July 2009)

INTERNATIONAL SEARCH REPORT		International application No. PCT/SG2013/000529	
Information on patent family members			
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Patent Document/s Cited in Search Report		Patent Family Member/s	
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