(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
3 January 2014 (03.01.2014)

WIPO | PCT

(10) International Publication Number
WO 2014/004588 A1

(51) International Patent Classification:
*B25J 15/08* (2006.01)

(21) International Application Number:
PCT/US2013/047727

(22) International Filing Date:
25 June 2013 (25.06.2013)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
61/664,091 25 June 2012 (25.06.2012) US
61/664,675 26 June 2012 (26.06.2012) US

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(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

**Published**:

— *with international search report (Art. 21(3))*

(54) **Title**: ROBOTIC FINGER

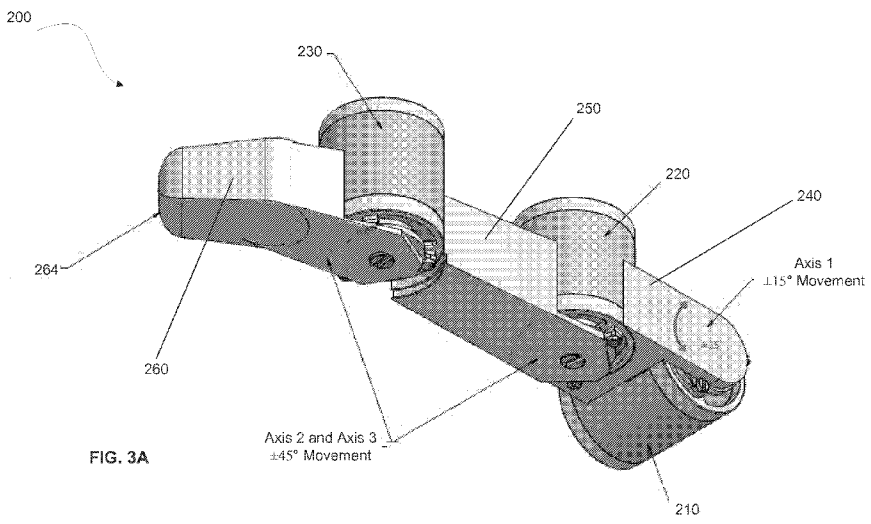


FIG. 3A

(57) **Abstract**: A robotic finger, comprising: a first axis of movement comprising a moving magnet; a second axis of movement comprising a moving coil, wherein the second axis is generally orthogonal to the first axis; and a third axis of movement comprising a moving magnet, wherein the third axis of movement is generally oriented in the same direction as the first axis of movement.

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# ROBOTIC FINGER

## Cross Reference to Related Applications

**[0001]** The present application claims the benefit of priority under 35 U.S.C. § 119(e) of United States Provisional Application Serial No. 61/664,091, entitled PROSTHETIC HAND, filed June 25, 2012, and of United States Provisional Application Serial No. 61/664,675, entitled PROSTHETIC HAND, filed due on June 26, 2012, the contents of each of which are hereby incorporated by reference in their entirety for all purposes.

## Field

**[0002]** This disclosure relates generally to robotics, and more particularly, to a robotic finger for a robotic hand with movement driven and controlled by moving coil or moving magnet actuators.

## Background

**[0003]** There are many tasks in the workplace today that are accomplished by human hands. Some tasks are very repetitive and cause carpal tunnel problems. Others take place in hazardous environments. Still others require extremely precise movements and are gradually becoming beyond the capability of humans. Prosthetic devices can be used to replace human hands in the above areas.

## Summary

**[0004]** The presently disclosed embodiments are directed to solving one or more of the problems presented in the prior art, as well as providing additional features that will become readily apparent by reference to the following detailed description when taken in conjunction with the accompanying drawings.

**[0005]** In one variation, a robotic finger comprises a first axis of movement, a second axis of movement, and a third axis of movement. The first axis of movement may be facilitated by a moving magnet. The second axis of movement may be facilitated by a moving coil, and the second axis may generally be orthogonal to the first axis. The third axis of movement may be facilitated by a moving magnet and the third axis of movement may generally be oriented in the same direction as the first axis of movement.

**[0006]** In another variation, a robotic finger comprises a distal elongate member, an intermediate elongate member, a proximal elongate member, and a plurality of actuators.

The distal elongate member may comprise a distal tip and a proximal tip. The intermediate elongate member may comprise a proximal tip and a distal tip, and the proximal tip of the distal elongate member may be coupled to the distal tip of the intermediate elongate member. The proximal elongate member may comprise a distal tip, and the proximal tip of the intermediate elongate member may be coupled to the distal tip of the proximal elongate member. The plurality of actuators may move the distal elongate member in a first direction by a rotating moving magnet actuator, may move the distal elongate member in a second direction generally orthogonal to the first direction by a moving coil actuator, and move the intermediate elongate member in the first direction by a rotating moving magnet actuator.

**[0007]** It is to be understood that both the foregoing general description and the following detailed description are exemplary and are merely intended to provide further explanation of the subject matter.

## Brief Description of the Drawings

**[0008]** The features, nature and advantages of the present disclosure will become more apparent from the detailed description set forth below when taken in conjunction with the drawings in which like reference characters identify correspondingly throughout and wherein:

**[0009]** Figure 1 illustrates a bottom view of a robotic finger in accordance with one disclosed embodiment.

**[0010]** Figure 2 illustrates a top view of the robotic finger of Figure 1.

**[0011]** Figures 3A and 3B respectively illustrate perspective and side views of a robotic finger in accordance with another disclosed embodiment.

**[0012]** Figures 4A-4C provide views of a brushless, moving coil motor capable of being utilized within the robotic finger of Figure 3.

## Detailed Description

**[0013]** In the following description of exemplary embodiments, reference is made to the accompanying drawings which form a part hereof, and in which it is shown by way of illustration specific embodiments in which the invention may be practiced. It is to be understood that other embodiments may be utilized and structural changes may be made without departing from the scope of the present invention.

**[0014]** The word "exemplary" is used herein to mean "serving as an example or illustration." Any aspect or design described herein as "exemplary" is not necessarily to be construed as preferred or advantageous over other aspects or designs.

**[0015]** It should be understood that the specific order or hierarchy of steps in the processes disclosed herein is an example of exemplary approaches. Based upon design preferences, it is understood that the specific order or hierarchy of steps in the processes may be rearranged while remaining within the scope of the present disclosure.

**[0016]** Reference will now be made in detail to aspects of the subject technology, examples of which are illustrated in the accompanying drawings, wherein like reference numerals refer to like elements throughout.

**[0017]** Disclosed herein are methods and systems for a robotic finger of a robotic hand, where the finger comprises at least three axes of movement driven by moving magnet or moving coil actuators. The use of moving magnet or moving coil actuators may provide a prosthetic device that better matches the movement and subtleties of the human hand.

**[0018]** In one variation, a robotic finger comprises a plurality of elongate members corresponding to one or more of the phalanges of a human finger. In some variations, a proximal, an intermediate, and a distal elongate member may correspond to a proximal, an intermediate, and a distal phalanx of a human finger. A distal tip of the proximal elongate member may be coupled to a proximal tip of the intermediate elongate member and a distal tip of the intermediate elongate member may be coupled to a proximal tip of the distal elongate member. The proximal elongate member may comprise a first and a second axis of movement. The intermediate elongate member may comprise a third axis of movement.

**[0019]** The first and second axis of movement of the proximal elongate member may be generally orthogonal. In some variations, the first axis of movement comprises a 100 degree range in a generally up and down plane. As used herein, the orientation of a robotic finger is taken so that the hand is prone, that is, the hand lies in a generally horizontal plane. The first

axis may use a rotating moving magnet actuator. In some variations, 24 or 48 DC power supplies are utilized for the rotating moving magnet actuator. The moving magnet design may have 4 magnets per side, located on 2 steel shafts projected out of the moving shaft. Static coils may be located in the static housing. In some variations, the coils may be designed so that a movement range of 100 degrees is achieved with a single pole. In other variations, a multipole arrangement may be arranged. The single pole may be easier to control, but the multipole may have a higher torque capability. A rotary encoder may be attached to one of the moving magnet discs. A rotary encoder reader head may be mounted opposite it on the static housing. This allows the rotary moving magnet motor to be used in servo mode. The rotating moving magnet actuator may be a direct drive actuator.

**[0020]** This arrangement may allow for programmable control of speed, position, and torque – which translates into force. In addition, this arrangement may have the benefit of eliminating moving cables since the coils and reader head are static.

**[0021]** The second axis of movement may comprise a 20 degree range in a side to side plane. The 20-degree angle may be accomplished by attaching a moving coil to the rear of the shaft associated with the first axis. The coil may move inside a magnet housing that is statically located in the static housing. The coil may be wound on a bobbin that has an inner opening large enough so that it clears the center pole even though the coil moves in a 20 degree arc. This may keep the moving mass of the moving shaft low since the magnet housing in not included. The second axis of movement may comprise an encoder, similar to the encoder discussed above with respect to the first axis of movement. The moving coil actuator may be a direct drive actuator.

**[0022]** Combining the first and second axis on the proximal elongate member results in the member being able to rotate 100 degrees about the first axis and pivot 20 degrees about the second axis. This range may simulate the positive and negative inflexion that results from muscle contraction in the human hand.

**[0023]** The third axis of movement of the intermediate elongate member may be oriented generally in the same direction as the first axis of the proximal elongate member. In some variations, the third axis of movement comprises a 100 degree range in a generally up and down plane. In some variations, the third axis of movement comprises a rotating moving magnet actuator similar to the rotating moving magnet actuator and encoder of the first axis of movement.

**[0024]** By using actuators, variations of the robotic finger can take advantage of the programmable force and object detection processes of actuators. The result may be a finger that more closely matches human finger capabilities and has additional useful features. Such additional features may include precise and measurable force control, position control, and speed control.

**[0025]** In some variations, cabling management is done in the following manner. The third axis has 8 lines – 6 for encoder and 2 for power. The moving shaft operated by the first and second axes has a hole thru the center. The third axis cable runs thru this hole and terminates on to a connector board. The second axis also has wiring that feeds thru the hole. All the wiring terminates onto a connector board. A flex cable running 16 lines connects the second and third axes' wires to a connector board statically mounted on the first axis. Male connectors on the board enable all axes to be connected to a separately mounted 3 axis servo controller.

**[0026]** In some variations, integrated springs are added to partially counterbalance heavy masses and return axis joints to a determined retracted or extended position when power is cut to the robotic finger.

**[0027]** In some variations, the moving magnet and moving coil elements are equipped with appropriately placed steel or magnets to achieve permanent "drag" for each axis. This means that each axis will remain in position when power is cut or reduced.

**[0028]** In some variations, a suction pump is added to provide picking capabilities. A vacuum channel can be run thru the open internal diameters of the shafts.

**[0029]** Figure 1 illustrates a bottom view of a robotic finger 100 in accordance with one embodiment. Robotic finger 100 includes three axes of movement—axis 1, axis 2, and axis 3—similar to the robotic finger described above. Although axis 1, axis 2, and axis 3 are illustrated as providing ranges of ±45 degrees, ±10 degrees, and ±45 degrees, respectively, other variations may have different ranges. Robotic finger 100 includes a cover 1, axis1 encoder code disk 2, axis1 encoder reader head 3, axis1 first magnet plate 4, axis1 second magnet plate 5, axis1 motor coil 6, axis1 coil bobbin 7, axis1 permanent magnet 8, axis1 rotary bearings 9, axis1 pivot shaft 10, a housing 11, axis2 pivot shaft 12, axis2 rotary bearings 13, axis2 encoder code disk 14, axis2 encoder reader head 15, axis2 linear angular motor 16, axis2 linear motor coil assembly 17, and a motor 19. Figure 2 illustrates a top view of the robotic finger 100 of Figure 1

**[0030]** Attention is now directed to Figure 3A, which illustrates a perspective view of a robotic finger 200 in accordance with another aspect of the disclosure. Robotic finger 200 includes three axes of movement—axis 1, axis 2, and axis 3—similar to robotic finger 100 described above. Although axis 1, axis 2, and axis 3 are illustrated as providing ranges of ±15 degrees, ±45 degrees, and ±45 degrees, respectively, other variations may have different ranges. As shown, robotic finger 200 includes an axis 1 motor 210, an axis 2 motor 220 and an axis 3 motor 230. During operation, the axis 1 motor 210 may move a first elongate member 240 though ±15 degrees about axis 1, the axis 2 motor may move a second elongate member 250 through ±45 degrees about axis 2, and the axis 3 motor may move a third elongate member 260 through ±45 degrees about axis 3. As shown, the third elongate member 260 includes a finger tip element 264.

**[0031]** Referring to Figure 3B, a side view is provided of the robotic finger 200. As shown, the finger 200 further includes an axis 1 encoder reader head 310, an axis 2 encoder reader head 320 and an axis 3 encoder reader head 330. The finger 200 further includes an axis 2 encoder code strip 324, an axis 3 encoder code strip 334, and an axis 1 encoder code strip (not shown) proximate the axis 1 encoder read head 310.

**[0032]** Figure 4A is a partially disassembled view of a brushless, moving coil motor 400 capable of being used to implement the axis 1 motor 210, the axis 2 motor 220 and/or the axis 3 motor 230. Figure 4B provides an end view of the motor 400. Figure 4C is a sectional view of the motor 400.

**[0033]** As shown in Figure 4C, the motor assembly 400 includes an iron core 410, permanent magnets 420, rotary bearings 430 and a cap structure 440. In one embodiment the motor assembly 400 includes 12 total coils (9 active), 8 magnets and 2 ball bearings. The coils in the assembly 400 may be of a total length of 49mm, and of an effective length of 9mm. A coil wire size of 36 copper may be used in a configuration with 151 turns (6 layers).

**[0034]** Although the present invention has been fully described in connection with embodiments thereof with reference to the accompanying drawings, it is to be noted that various changes and modifications will become apparent to those skilled in the art. Such changes and modifications are to be understood as being included within the scope of the present invention. The various embodiments of the invention should be understood that they have been presented by way of example only, and not by way of limitation. Likewise, the various diagrams may depict an example architectural or other configuration for the

invention, which is done to aid in understanding the features and functionality that can be included in the invention. The invention is not restricted to the illustrated example architectures or configurations, but can be implemented using a variety of alternative architectures and configurations. Additionally, although the invention is described above in terms of various exemplary embodiments and implementations, it should be understood that the various features and functionality described in one or more of the individual embodiments are not limited in their applicability to the particular embodiment with which they are described. They instead can, be applied, alone or in some combination, to one or more of the other embodiments of the invention, whether or not such embodiments are described, and whether or not such features are presented as being a part of a described embodiment. Thus the breadth and scope of the invention should not be limited by any of the above-described exemplary embodiments.

**[0035]** Terms and phrases used in this document, and variations thereof, unless otherwise expressly stated, should be construed as open ended as opposed to limiting. As examples of the foregoing: the term "including" should be read as meaning "including, without limitation" or the like; the term "example" is used to provide exemplary instances of the item in discussion, not an exhaustive or limiting list thereof; and adjectives such as "conventional," "traditional," "normal," "standard," "known", and terms of similar meaning, should not be construed as limiting the item described to a given time period, or to an item available as of a given time. But instead these terms should be read to encompass conventional, traditional, normal, or standard technologies that may be available, known now, or at any time in the future. Likewise, a group of items linked with the conjunction "and" should not be read as requiring that each and every one of those items be present in the grouping, but rather should be read as "and/or" unless expressly stated otherwise. Similarly, a group of items linked with the conjunction "or" should not be read as requiring mutual exclusivity among that group, but rather should also be read as "and/or" unless expressly stated otherwise. Furthermore, although items, elements or components of the invention may be described or claimed in the singular, the plural is contemplated to be within the scope thereof unless limitation to the singular is explicitly stated. For example, "at least one" may refer to a single or plural and is not limited to either. The presence of broadening words and phrases such as "one or more," "at least," "but not limited to", or other like phrases in some instances shall not be read to mean that the narrower case is intended or required in instances where such broadening phrases may be absent.

**[0036]** Additionally, memory or other storage, as well as communication components, may be employed in embodiments of the invention. It will be appreciated that, for clarity purposes, the above description has described embodiments of the invention with reference to different functional units and processors. However, it will be apparent that any suitable distribution of functionality between different functional units, processing logic elements or domains may be used without detracting from the invention. For example, functionality illustrated to be performed by separate processing logic elements, or controllers, may be performed by the same processing logic element, or controller. Hence, references to specific functional units are only to be seen as references to suitable means for providing the described functionality, rather than indicative of a strict logical or physical structure or organization.

We Claim:

1. A prosthetic finger, comprising:

a first axis of movement comprising a moving magnet;

a second axis of movement comprising a moving coil, wherein the second axis is generally orthogonal to the first axis; and

a third axis of movement comprising a moving magnet, wherein the third axis of movement is generally oriented in the same direction as the first axis of movement.

2. A prosthetic finger, comprising:

a distal elongate member comprising a distal tip and a proximal tip;

an intermediate elongate member comprising a proximal tip and a distal tip, wherein the proximal tip of the distal elongate member is coupled to the distal tip of the intermediate elongate member;

a proximal elongate member comprising a distal tip, wherein the proximal tip of the intermediate elongate member is coupled to the distal tip of the proximal elongate member; and

a plurality of actuators, wherein the distal elongate member is moved in a first direction by a rotating moving magnet actuator, wherein the distal elongate member is moved in a second direction generally orthogonal to the first direction by a moving coil actuator, and wherein the intermediate elongate member is moved in the first direction by a rotating moving magnet actuator.

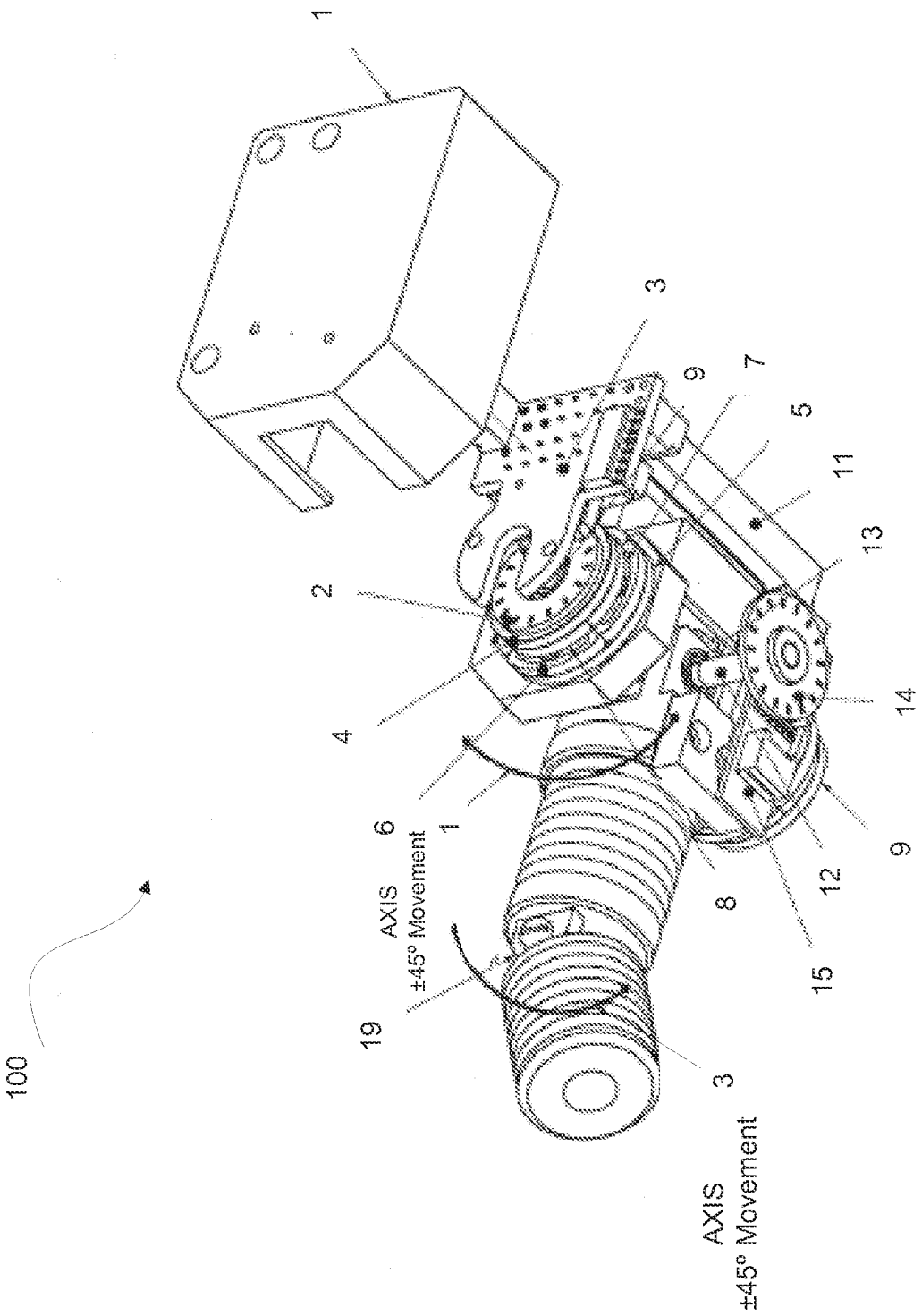
100
19
AXIS
±45° Movement
6
1
4
2
1
3
9
7
5
11
13
14
9
12
15
8
3
AXIS
±45° Movement

FIG. 1

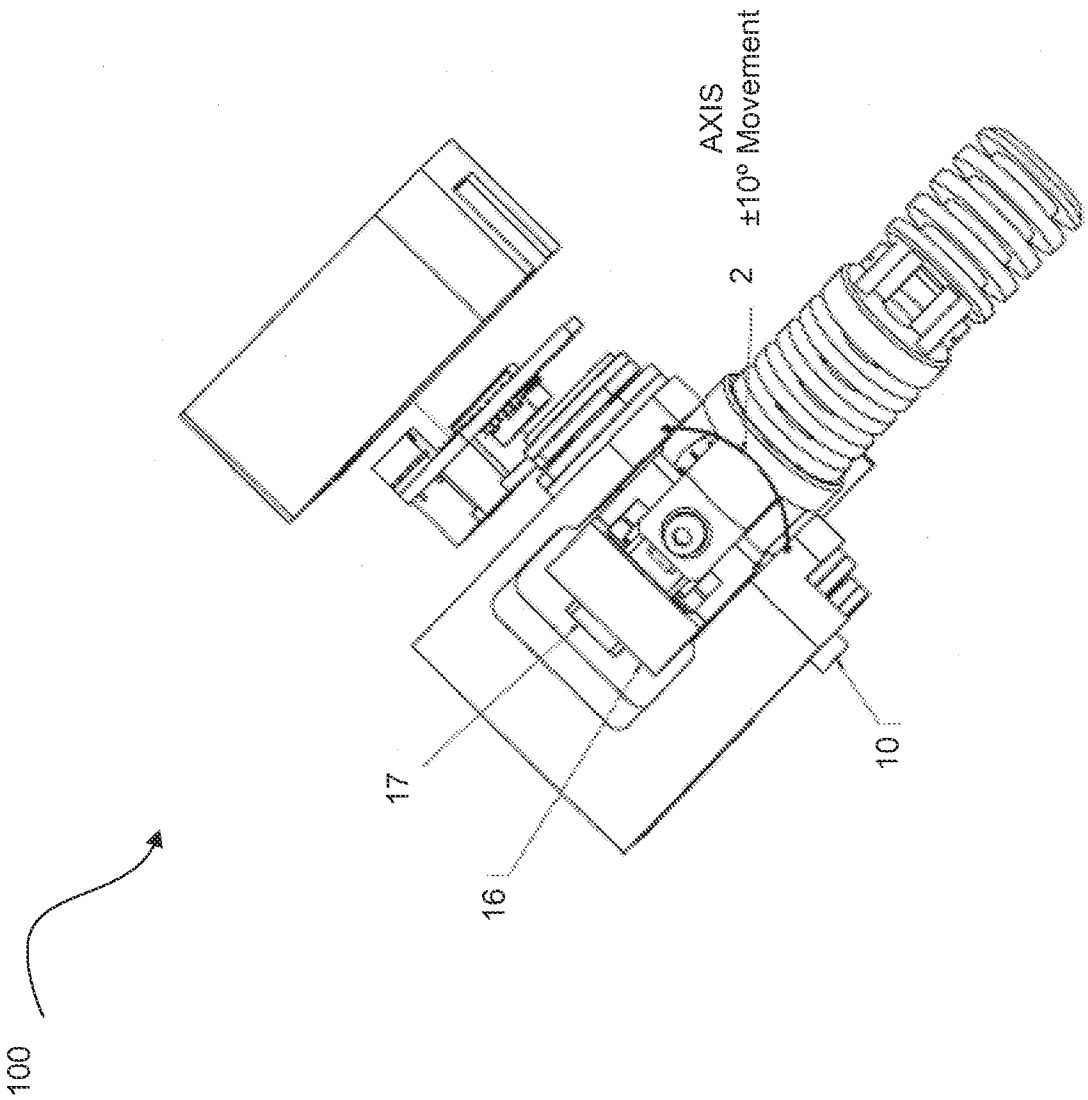


FIG. 2

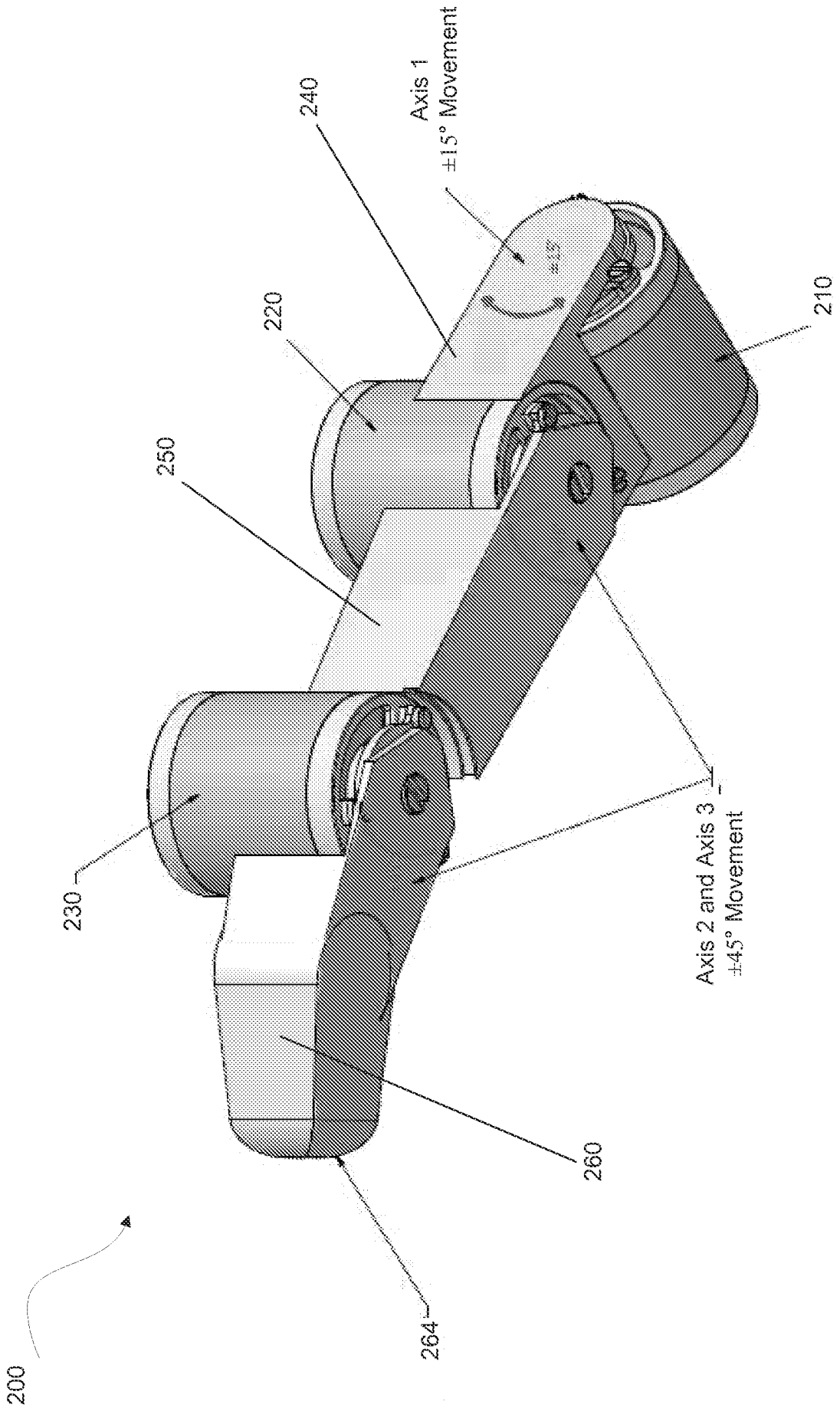
200
264
260
230
Axis 2 and Axis 3
±45° Movement
250
220
240
Axis 1
±15° Movement
210

FIG. 3A

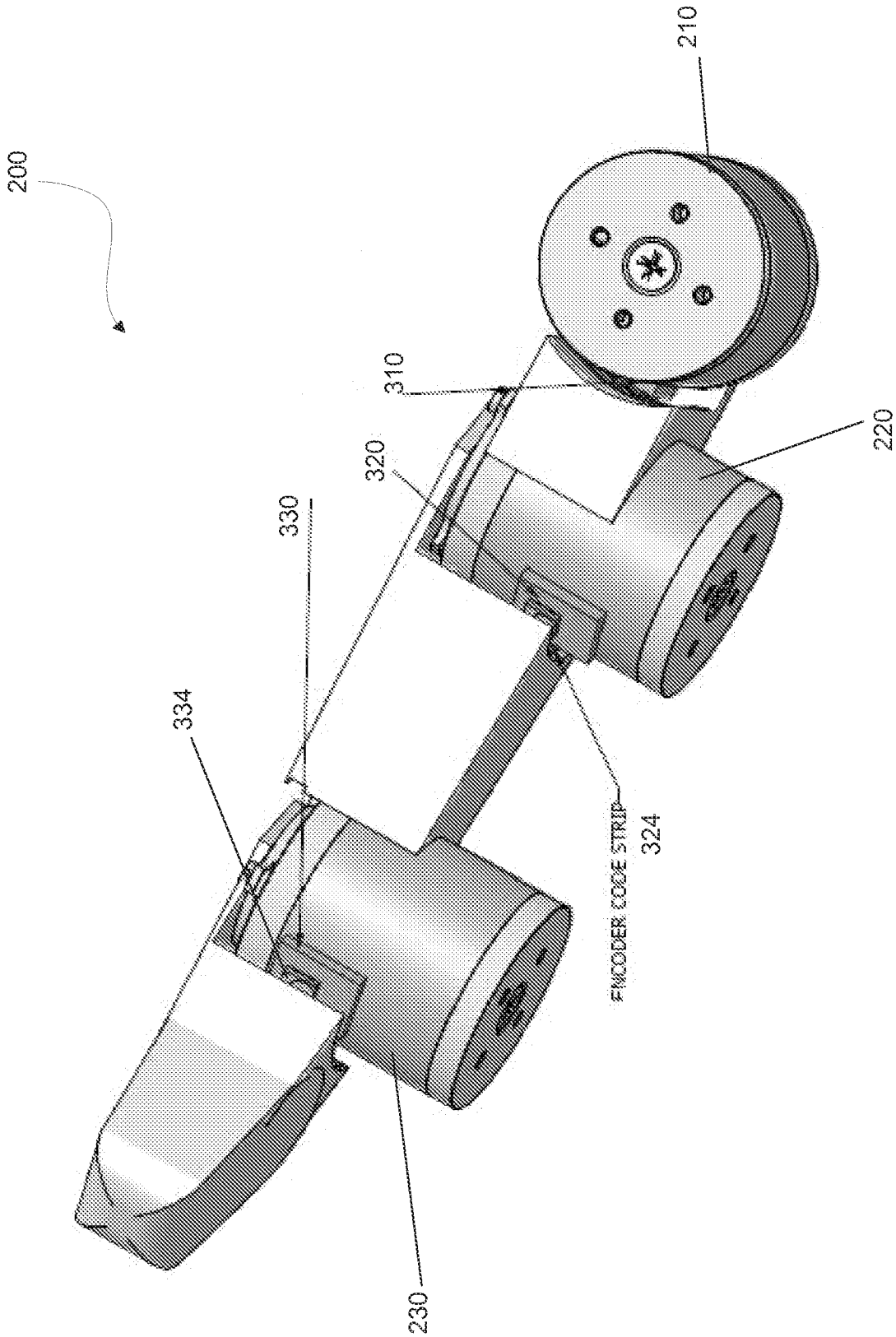


FIG. 3B

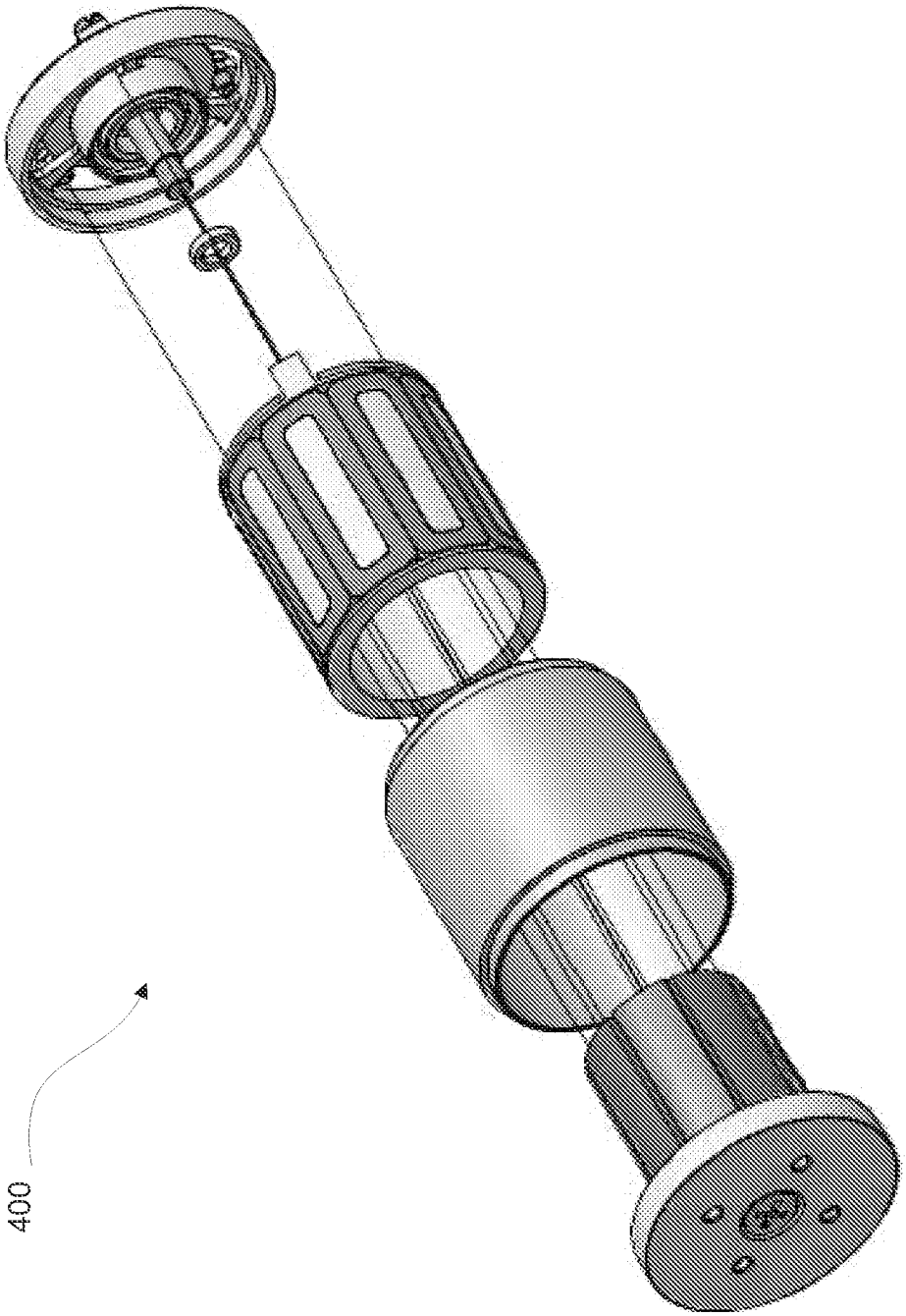


FIG. 4A

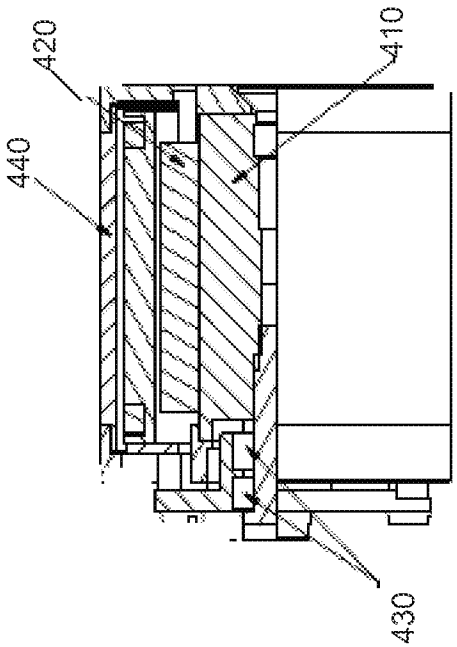


FIG. 4C

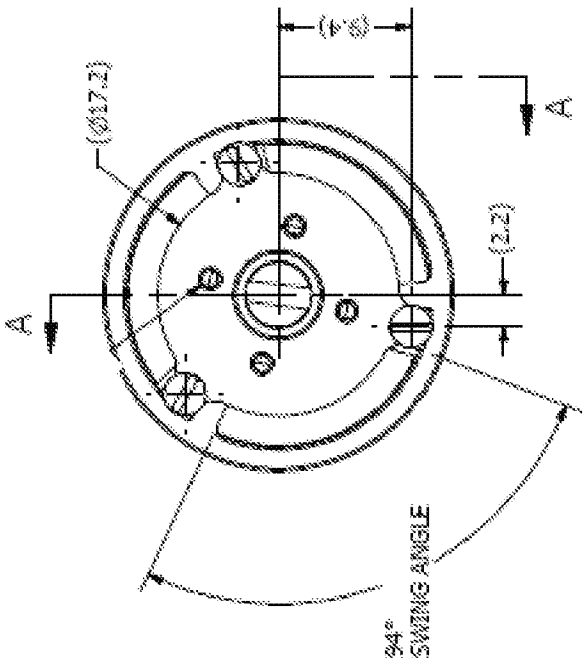


FIG. 4B

**INTERNATIONAL SEARCH REPORT**

International application No.
**PCT/US2013/047727**

**A. CLASSIFICATION OF SUBJECT MATTER**

**B25J 15/08(2006.01)i**

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)
B25J 15/08; B25J 19/06; B25J 15/10; B25J 17/00; A61F 2/58; A61F 2/68; B25J 9/06; B25J 19/00

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
Korean utility models and applications for utility models
Japanese utility models and applications for utility models

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
eKOMPASS(KIPO internal) & Keywords: finger, robot, actuator, magnet, moving coil

**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.

☒ See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
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"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents,such combination being obvious to a person skilled in the art
"&" document member of the same patent family

| Date of the actual completion of the international search | Date of mailing of the international search report |
|---|---|
| 15 October 2013 (15.10.2013) | **16 October 2013 (16.10.2013)** |


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**INTERNATIONAL SEARCH REPORT**

Information on patent family members

International application No.
**PCT/US2013/047727**

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| | | EP 2528549 B1 | 05/06/2013 |
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| | | JP 2011-067931 A | 07/04/2011 |
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| | | US 2013-193704 A1 | 01/08/2013 |
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