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MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM,
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(54) Title: HUMANOID LOWER BODY ROBOT ELECTRO HYDROSTATIC ACTUATING KNEE

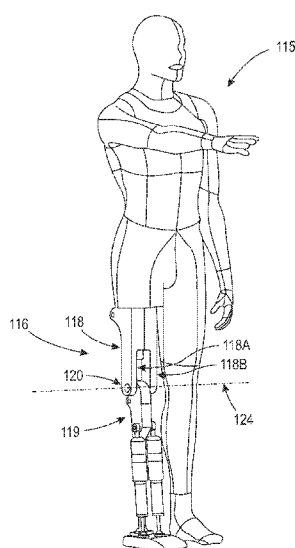


FIG. 1

(57) **Abstract:** A robotic knee (116) comprising an upper leg (118) and a lower leg (119) configured to rotate about a knee axis (124) relative to the upper leg (118), a motor (131), a hydraulic pump (132) driven by the motor (131), a hydraulic piston assembly (133) hydraulically connected to the pump (132) and comprising a housing (134) and an actuating rod (138) connected to a piston (137) separating first and second chambers in the housing (134), one of the housing (134) or the actuating rod (138) connected to the upper leg (118) and the other of the housing (134) or the actuating rod (138) connected to the lower leg (119), and the piston assembly (133) configured to actuate the lower leg (119) relative to the upper leg (118) about the knee axis (124), wherein rotation of the lower leg (119) relative to the upper leg (118) about the knee axis (124) is controllable by the motor (131).

HUMANOID LOWER BODY ROBOT ELECTRO HYDROSTATIC ACTUATING KNEE

TECHNICAL FIELD

[0001] The present disclosure relates generally to the field of humanoid robotic joints, and more particularly to an electro hydrostatic actuated humanoid robotic knee joint.

BACKGROUND ART

[0002] Humanoid robots are known in the prior art. Such robots are provided with joints designed to allow for the robot to move in a manner resembling human movement. For example, U.S. Patent No. 9,327,785, entitled “Humanoid Robot Implementing a Ball and Socket Joint,” is directed to a humanoid robot ankle joint comprising two elements connected by a spherical joint with three degrees of freedom in rotation, the joint being moved by three actuators each acting in one of the three degrees of freedom.

BRIEF SUMMARY

[0003] With parenthetical reference to the corresponding parts, portions or surfaces of the disclosed embodiment, merely for purposes of illustration and not by way of limitation, an improved robotic knee (116) is provided comprising: an upper leg member (118); a lower leg member (119); an knee joint (120) between the upper leg member and the lower leg member; the knee joint having a knee pivot center (123); the lower leg member configured to rotate about a knee axis (124) extending through the knee pivot center; an electric motor (131) adapted to be supplied with a current and to operatively provide a torque on an output shaft (140); a hydraulic pump (132) driven by the output shaft of the electric motor; a hydraulic piston assembly (133) hydraulically connected to the hydraulic pump and comprising a housing (134) having a first chamber (135) and a second chamber (136), and a piston (137) separating the first and second chambers of the housing; an actuating rod (138) connected to the piston and configured to move linearly with the piston relative to the housing; one of the housing or the actuating rod connected to the upper leg member and the other of the housing or the actuating rod connected to the lower leg member; the hydraulic piston assembly configured to actuate the lower leg member relative to the upper leg member within a range of motion about the knee axis; wherein rotation of the lower leg member relative to the upper leg member about the knee axis is controllable by the electric motor.

[0004] The electric motor may be a variable speed bidirectional electric motor adapted to operatively provide a torque on the first output shaft at varying speeds and by direction, the hydraulic pump may be a reversible variable speed hydraulic pump, and rotation of the lower leg member relative to the upper leg member about the knee axis may be controllable by adjusting the speed and/or direction of the variable speed bidirectional electric motor. The electric motor may comprise a brushless DC servo-motor. The hydraulic pump may be selected from a group consisting of a fixed displacement pump, a variable displacement pump, a two-port pump, and a three-port pump.

[0005] The piston may comprise a first surface area exposed to the first chamber of the housing and a second surface area exposed to the second chamber of the housing, and the first surface area may be substantially equal to the second surface area. The housing may comprise a cylinder having a first end wall, the piston may be disposed in the cylinder for sealed sliding movement therealong, and the actuator rod may be connected to the piston for movement therewith and may comprise a portion sealingly penetrating the first end wall.

[0006] The robotic knee may comprise a controller (150) that receives input signals and outputs command signals to the electric motor to control rotation of the lower leg member relative to the upper leg member about the knee axis. The robotic knee may comprise a regenerative power stage (156) to the electric motor and the electric motor may be controlled by the controller to operate in a regeneration mode. The robotic knee may comprise an electric storage device (155) connected to the electric motor. The robotic knee may comprise a position sensor (151) configured to sense a position of the piston and to provide an input signal to the controller (150).

[0007] The housing (134) may be connected to the upper leg member and the actuating rod (138) may be connected to the lower leg member. The actuating rod (238) may be connected to the upper leg member and the housing (234) may be connected to the lower leg member.

[0008] The robotic knee may comprise a fluid reservoir (141) connected to the hydraulic pump and the hydraulic piston assembly, and the hydraulic pump, the hydraulic piston assembly and the reservoir may be connected in a substantially closed hydraulic system.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] FIG. 1 is a representative perspective view of a first embodiment of an improved humanoid robot.

[0010] FIG. 2 is a right view of the humanoid robot shown in FIG. 1.

[0011] FIG. 3 is a right view of the humanoid robot shown in FIG. 1 with the right knee bent.

[0012] FIG. 4 is an enlarged right view of the robotic knee shown in FIG. 2.

[0013] FIG. 5 is a partial cutaway view of the robotic knee shown in FIG. 4.

[0014] FIG. 6 is a view of the robotic knee shown in FIG. 4 bent 135 degrees about its knee axis.

[0015] FIG. 7 is a partial cutaway view of the robotic knee shown in FIG. 6.

[0016] FIG. 8 is a schematic system diagram of the electro-hydraulic actuator system shown in FIG. 2.

[0017] FIG. 9 is a schematic diagram of the electro-hydraulic actuator unit shown in FIG. 8.

[0018] FIG. 10 is a view of an alternative embodiment of the robotic knee shown in FIG. 4.

DETAILED DESCRIPTION OF THE EMBODIMENTS

[0019] At the outset, it should be clearly understood that like reference numerals are intended to identify the same structural elements, portions or surfaces consistently throughout the several drawing figures, as such elements, portions or surfaces may be further described or explained by the entire written specification, of which this detailed description is an integral part. Unless otherwise indicated, the drawings are intended to be read (e.g., crosshatching, arrangement of parts, proportion, degree, etc.) together with the specification, and are to be considered a portion of the entire written description. As used in the following description, the terms "horizontal", "vertical", "left", "right", "up" and "down", as well as adjectival and adverbial derivatives thereof (e.g., "horizontally", "rightwardly", "upwardly", etc.), simply refer to the orientation of the illustrated structure as the particular drawing figure faces the reader. Similarly, the terms "inwardly" and "outwardly" generally refer to the orientation of a surface relative to its axis of elongation, or axis of rotation, as appropriate.

[0020] Referring to the drawings, and more particularly to FIGS. 1-3, an improved robotic knee is provided, of which a first embodiment is generally indicated at 116. In this embodiment, robotic knee 116 is part of humanoid robot 115 and generally comprises upper leg member 118 connected at pivot joint 120 to lower leg member 119.

[0021] As shown in FIGS. 1 and 4-7, pivot joint 120 comprises yoke arms 118A and 118B formed in the lower end of upper leg member 118 and pivot shaft 123A orientated on knee axis 124 and extending transversely between yoke arms 118A and 118B. Pivot shaft 123A also extends through a pivot hole in the top end of lower leg member 119 orientated on knee

axis 124. Thus, lower leg member 119 is rotationally supported by shaft 123A such that lower leg member 119 is free to rotate about pivot axis 124 relative to upper leg member 118.

[0022] Knee actuator system 117 actuates lower leg 119 relative to upper leg 118 at joint 120. Knee actuator system 117 includes hydrostatic actuator 130. Referring now to FIG. 8, actuator 130 of actuator system 117 is schematically indicated as including variable speed bidirectional electric servomotor 131, bidirectional or reversible pump 132 driven by motor 131, and double-acting hydraulic piston assembly 133. Controller 150 supplies a signal to regenerative power stage 156, which in turn supplies a current of the appropriate magnitude and polarity to motor 131.

[0023] FIG. 9 is a schematic view for electro-hydraulic actuator 130. As described above and with reference to FIG. 9, actuator 130 includes variable speed bidirectional electric servomotor 131, bidirectional or reversible pump 132 driven by motor 131, and double-acting hydraulic piston assembly 133. In this embodiment, motor 131 is a brushless D.C. variable-speed servo-motor that is supplied with a current. Motor 131 has an inner rotor with permanent magnets and a fixed non-rotating stator with coil windings. When current is appropriately applied through the coils of the stator, a magnetic field is induced. The magnetic field interaction between the stator and rotor generates torque which may rotate output shaft 140. When the supplied current is of one polarity, the motor will rotate in one direction. When the supplied current supplied is of the opposite polarity, the motor will rotate in the opposite direction. Accordingly, motor 131 will selectively apply a torque on its output shaft 140 in one direction about axis x-x at varying speeds and will apply a torque on its output shaft 140 in the opposite direction about axis x-x at varying speeds. Other motors may be used as alternatives. For example, a variable speed stepper motor, brush motor or induction motor may be used.

[0024] In this embodiment, pump 132 is a fixed displacement bi-directional internal two-port gear pump. The pumping elements, namely gears, are capable of rotating in either direction, thereby allowing hydraulic fluid to flow in either direction. This allows for oil to be added into and out of the system as the system controller closes the control loop of position or pressure. The shaft of at least one gear of pump 132 is connected to output shaft 140 of motor 131 with the other pump gear following. The direction of flow of pump 132 depends on the direction of rotation of motor 131 and output shaft 140. In addition, the speed and output of pump 132 is variable with variations in the speed of motor 131. Other bi-

directional pumps may be used as alternatives. For example, a variable displacement pump may be used.

[0025] In this embodiment, hydraulic piston assembly 133 includes piston 137 slidably disposed within cylindrical housing 134 such that piston 137 may be driven in both directions relative to housing 134. Piston 137 sealingly separates left chamber 135 from right chamber 136. As shown in FIG. 9, one side or port 142 of pump 132 communicates with left chamber 135 via fluid line 144 and the opposite side or port 143 of pump 132 communicates with right chamber 136 via fluid line 145. Piston 137 is connected to actuating rod 138. Bidirectional motor 131 turns bidirectional pump 132 and bidirectional pump 132 is hydraulically connected to equal area piston actuator 133. Pump 132 and piston actuator 133 are a hydrostatic transmission, so as pump 132 spins in a first direction, piston 137 and rod 138 move in a first direction and as pump 132 spins in the other direction, piston 137 and rod 138 move in the other direction. Thus, piston 137 will extend or move rod 138 to the left when bidirectional motor 131 is rotated in a first direction, thereby rotating bidirectional pump 132 in a first direction and drawing fluid through port 142 from line 144 and chamber 135. Piston 137 will retract rod 138 or move to the right when bidirectional motor 131 is rotated in the other direction, rotating bidirectional pump 132 in the other direction and drawing fluid through port 143 from line 145 and chamber 136.

[0026] In this embodiment, oil reservoir 141 compensates for thermal oil expansion and contraction within the system and is controlled by check valves 146A and 146B. Connection ports 148A and 148B are used to fill the system with oil. Line 149 provides a pump casing leakage relief conduit to reservoir 141. The electrohydraulic actuator is a closed hydraulic system in that fluid is not supplied to the system from an external source in operation. Nor is fluid permitted to drain to an external sump in operation. Rather, reservoir 141 is either discharged or recharged, as appropriate, to accommodate differential fluid volumes. Motor 131 is required to provide torque and consume power when motions work against gravity.

[0027] Controller 150 receives feedback from sensors in the system and controls motor 131. Controller 150 controls the current to motor 131 at the appropriate magnitude and direction. With reference to FIG. 8, motor controller 150 supplies current command signal 158 to power stage 156, which in turn supplies current of the appropriate magnitude and polarity to motor 131, with such commands based in part on angular position feedback from resolver 161. Thus, controller 150 provides commands to vary the speed and direction of motor 131. The positions of rod 138 is monitored via position transducer 151, and the position signals are

then fed back to motor controller 150. In addition or alternatively, the pressure in lines 144 and 145 to chambers 135 and 136 may be monitored with pressure transducers, and the pressure signals may be fed back to motor controller 150. Variable speed bidirectional motor 131 and pump 132 control the speed and force of piston 137, and in turn rod 138, by changing the flow and pressure acting on piston 137. This is accomplished by looking at the feedback of position transducer 151 and/or pressure transducers and then closing the control loop by adjusting the speed and direction of motor 131. While in this embodiment position sensor 151 is a magnetostrictive linear position sensor, other position sensors may be used. For example, an LVDT position sensor may be used as an alternative.

[0028] As shown, the top end of cylinder housing 134 of actuator unit 130 is pivotally connected at pivot connection 126 to upper leg portion 118. As shown in FIG. 5, pivot connection 126 is offset up upper leg 118 from knee center 123 on imaginary line 170, which intersects the center of pivot connection 126 and knee center 123, by distance 173.

[0029] The outer end of actuating rod 138 of actuator unit 130 is pivotally connected at pivot connection 128 to lower leg portion 119. As shown in FIG. 5, pivot connection 128 is offset down lower leg 119 from knee center 123 on imaginary line 171, which intersects the center of pivot connection 128 and knee center 123, by distance 172. As shown in FIG. 5, in the non-bent position pivot line 170 and pivot line 171 are angularly separated or offset about knee center 123 by angle 174. Angle 174 is less than 180 degrees in the non-bent position. In this embodiment, angle 174 is about 135 degrees in the non-bent position. However, it is contemplated that angular displacement 174 and distances 172 and 173 could be varied depending on the desired dynamics.

[0030] Accordingly, connections 126 and 128 are located relative to knee joint 120 and joint center 123 so that actuator 130 may be controlled to rotate lower leg portion 119 up or down about knee axis 24 relative to upper leg portion 118. As shown in FIG. 7, in the fully-bent position pivot line 170 and pivot line 171 are nearly angularly aligned and angular displacement 174 has been reduced to about 5 degrees or less in this embodiment. However, it is contemplated that the operational angular of angular displacement 174, and distances 172 and 173, could be varied depending on the desired dynamics. Thus, in this embodiment knee actuator system 117 provides 135 degrees of angular movement between upper leg portion 118 and lower leg portion 119 of knee joint 116.

[0031] With reference to FIG. 8, when actuator 130 needs to absorb gravitational forces and impact forces, motor 131 is configured to operate as an electric generator that converts torque

generated from such forces on the system into electricity that is stored in battery or capacitor bank 155. Thus, actuator system 117 includes regenerative energy functionality. As shown, motor controller 150 supplies current command 158 to regenerative power stage 156, which in turn supplies the current at an appropriate magnitude and polarity to motor 131 to power electro-hydraulic actuator 130. The position of piston 137 or actuator rod 138 of actuator 130 is monitored via linear feedback position sensor 151, and such position signals are then fed back to motor controller 150. In this manner, system 117 controls the motion of humanoid robotic knee joint 116 during the active or “power stroke of the joint.” A significant percentage of the total motion is resisting the effects of a gravity load. During the “regenerative stroke of the joint,” the effects of gravity will generate a force on piston 137 of hydraulic actuator 130, which in turn produces pressure on pump 132, which in turn produces a torque on shaft 140 and to servomotor 131. Under these conditions and in the regenerative mode, electric motor 131 is configured to act as an electric generator. Regenerative power stage 156 and motor controller 150 detect the armature current 159 generated by motor 131 in this capacity and transfers such current of the appropriate magnitude and polarity of motor 131 into battery 155. Such stored electrical energy may then be used to power motor 131 and control the movement of electro-hydraulic actuator 117 in the active or “power stroke of the joint” mode. Since a humanoid robot may have limited battery power capacity, capturing regenerative power is beneficial. This regenerative power circuit takes advantage of a mode in which motor 131 is controlled to operate as a generator in a regeneration mode.

[0032] FIGS. 1-9 show an embodiment 116 in which housing 134 of actuator unit 130 is connected to upper leg 118 and actuation rod 138 of actuator unit 130 is connected to lower leg 119. However, it is contemplated that this arrangement may be reversed such that the housing of actuator unit 130 is connected to lower leg 119 and the actuating rod of actuator unit 130 is connected to upper leg 118. FIG. 10 shows an alternative embodiment 216 in which housing 234 of actuator unit 230 is connected to lower leg 119 and actuating rod 238 of actuator unit 230 is connected to upper leg 118. As shown, in this embodiment the bottom end of cylinder housing 234 of actuator unit 230 includes a pivot hole and is rotationally connected at pivot joint 228 to lower leg portion 119. The outer end of actuating rod 238 of actuator unit 230 is pivotally connected at pivot connection 226 to upper leg portion 118.

[0033] While the presently preferred form of an improved robotic knee has been shown and described, and several modifications thereof discussed, persons skilled in this art will readily

appreciate that various additional changes and modifications may be made without departing from the scope of the invention, as defined and differentiated by the claims.

CLAIMS

What is claimed is:

1. A robotic knee comprising:
 - an upper leg member;
 - a lower leg member;
 - a knee joint between said upper leg member and said lower leg member;
 - said knee joint having a knee pivot center;
 - said lower leg member configured to rotate about a knee axis extending through said knee pivot center;
 - an electric motor adapted to be supplied with a current and to operatively provide a torque on an output shaft;
 - a hydraulic pump driven by said output shaft of said electric motor;
 - a hydraulic piston assembly hydraulically connected to said hydraulic pump and comprising a housing having a first chamber and a second chamber, and a piston separating said first and second chambers of said housing;
 - an actuating rod connected to said piston and configured to move linearly with said piston relative to said housing;
 - one of said housing or said actuating rod connected to said upper leg member and the other of said housing or said actuating rod connected to said lower leg member;
 - said hydraulic piston assembly configured to actuate said lower leg member relative to said upper leg member within a range of motion about said knee axis; and
 - wherein rotation of said lower leg member relative to said upper leg member about said knee axis is controllable by said electric motor.
2. The robotic knee set forth in claim 1, wherein said electric motor is a variable speed bidirectional electric motor adapted to operatively provide a torque on said output shaft at varying speeds and by direction, said hydraulic pump is a reversible variable speed hydraulic pump, and rotation of said lower leg member relative to said upper leg member about said knee axis is controllable by adjusting said speed and/or direction of said variable speed bidirectional electric motor.
3. The robotic knee set forth in claim 1, wherein said first electric motor comprises a brushless DC servo-motor.

4. The robotic knee set forth in claim 1, wherein said hydraulic pump is selected from a group consisting of a fixed displacement pump, a variable displacement pump, a two-port pump, and a three-port pump.
5. The robotic knee set forth in claim 1, wherein said piston comprises a first surface area exposed to said first chamber of said housing and a second surface area exposed to said second chamber of said housing.
6. The robotic knee set forth in claim 5, wherein said first surface area is substantially equal to said second surface area.
7. The robotic knee set forth in claim 1, wherein said housing comprises a cylinder having a first end wall, wherein said piston is disposed in said cylinder for sealed sliding movement therealong, and wherein said actuator rod is connected to said piston for movement therewith and comprises a portion sealingly penetrating said first end wall.
8. The robotic knee set forth in claim 1, comprising a controller that receives input signals and outputs command signals to said electric motor to control rotation of said lower leg member relative to said upper leg member about said knee axis.
9. The robotic knee set forth in claim 8, comprising a regenerative power stage to said electric motor and wherein said electric motor may be controlled by said controller to operate in a regeneration mode.
10. The robotic knee set forth in claim 9, comprising an electric storage device connected to said electric motor.
11. The robotic knee set forth in claim 8, comprising a position sensor configured to sense a position of said first piston and to provide an input signal to said controller.
12. The robotic knee set forth in claim 1, wherein said housing is connected to said upper leg member and said actuating rod is connected to said lower leg member.
13. The robotic knee set forth in claim 1, wherein said actuating rod is connected to said upper leg member and said housing is connected to said lower leg member.

14. The robotic knee set forth in claim 1, comprising a fluid reservoir connected to said hydraulic pump and said hydraulic piston assembly and wherein said hydraulic pump, said hydraulic piston assembly and said reservoir are connected in a substantially closed hydraulic system.

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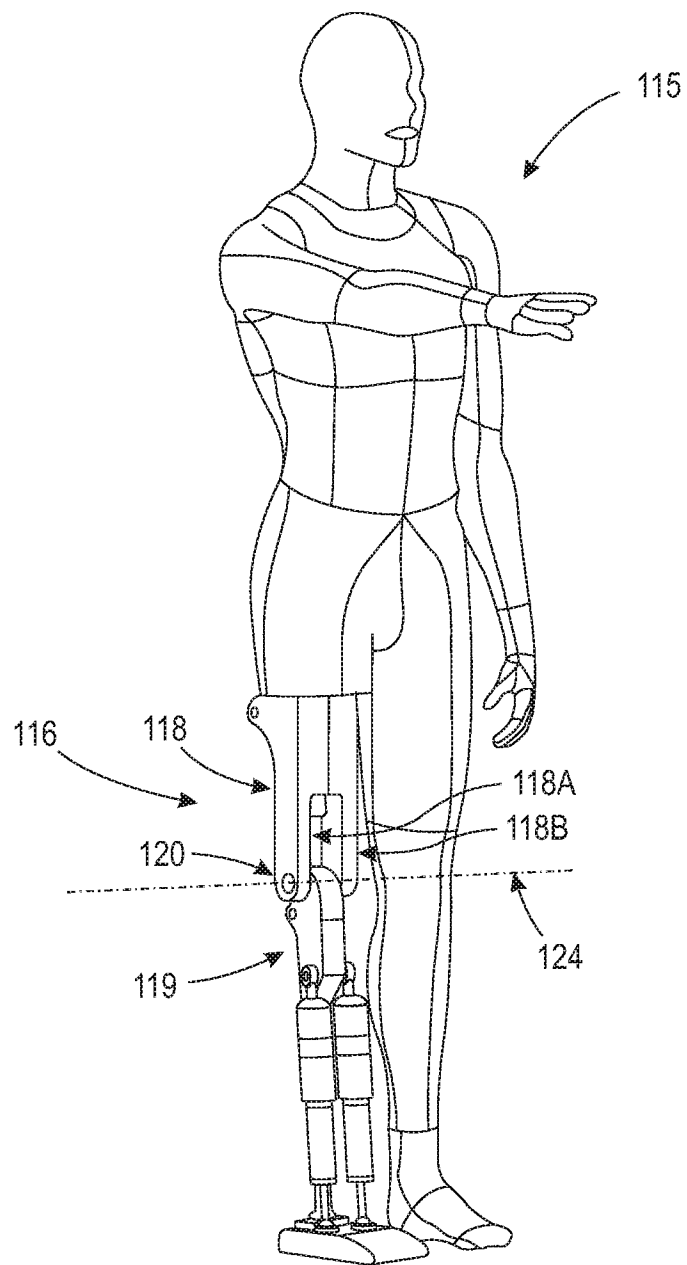


FIG. 1

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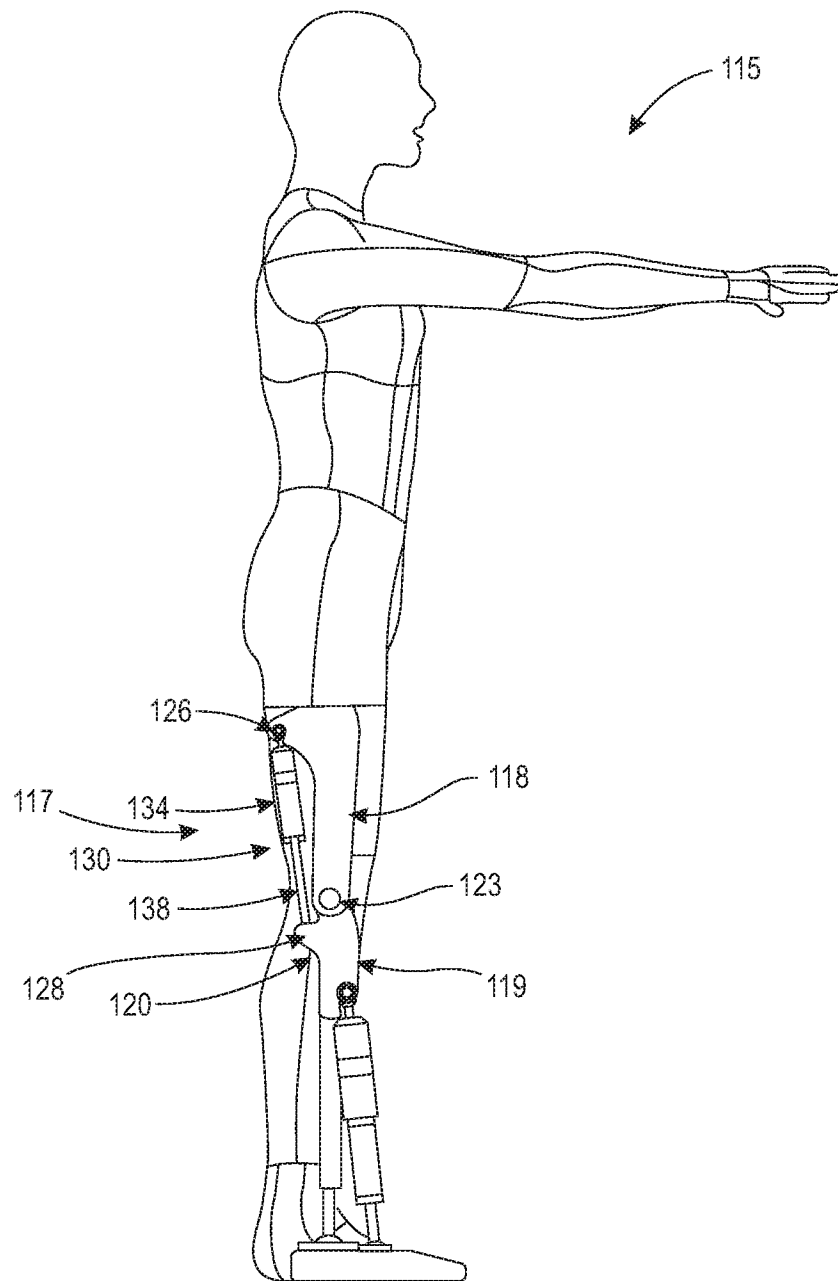


FIG. 2

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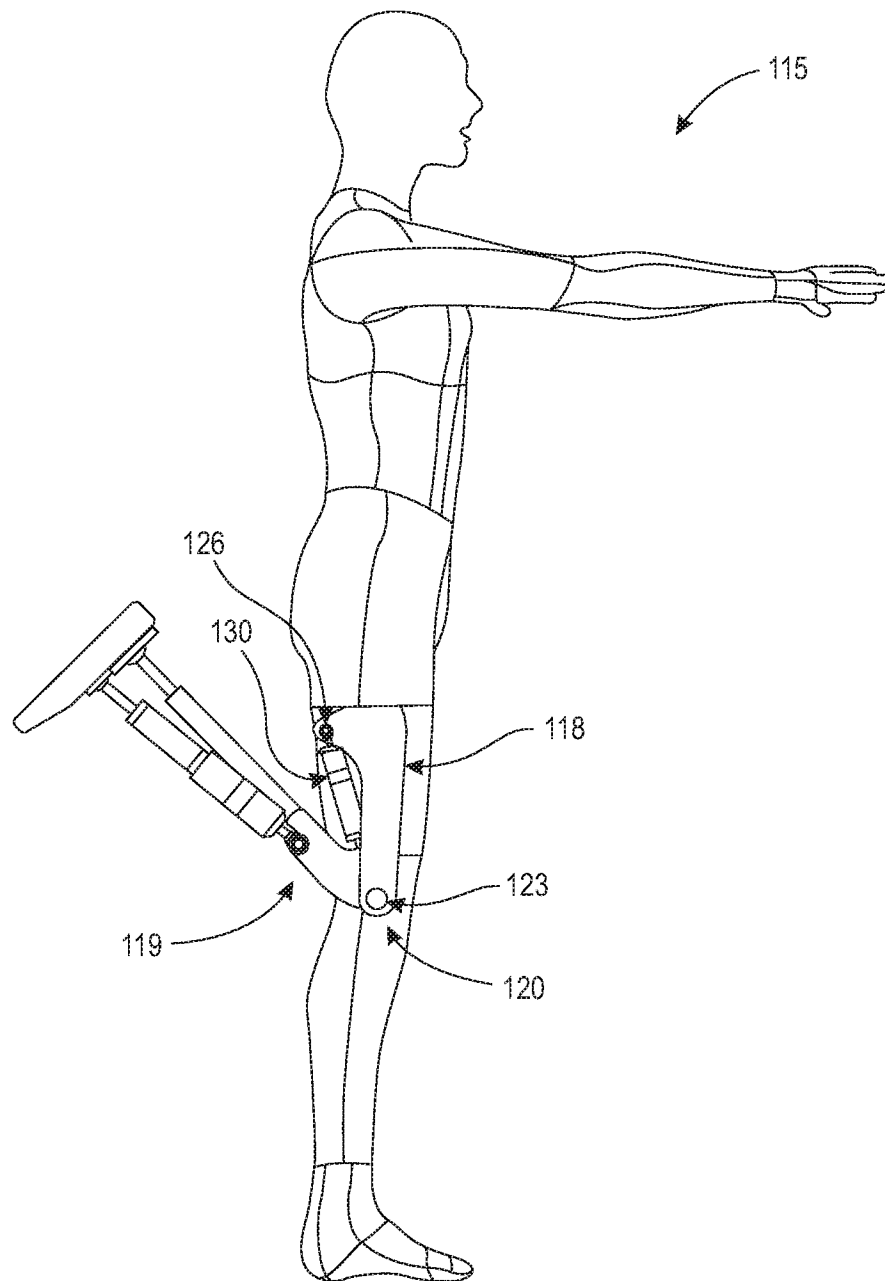


FIG. 3

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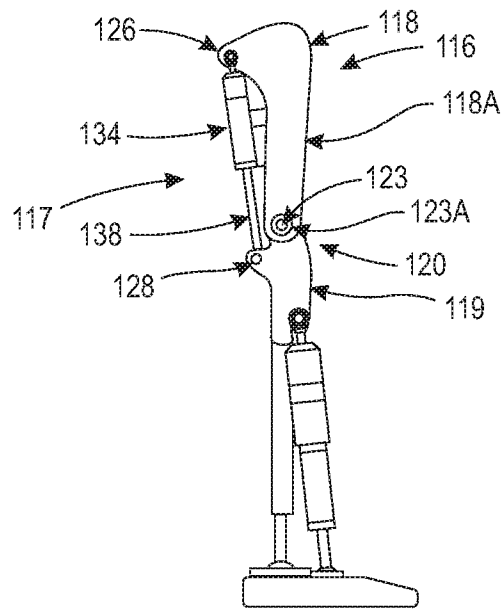


FIG. 4

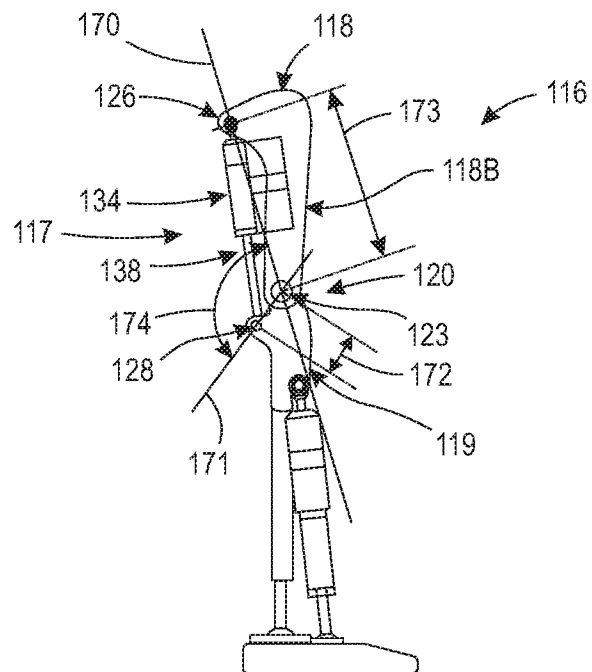


FIG. 5

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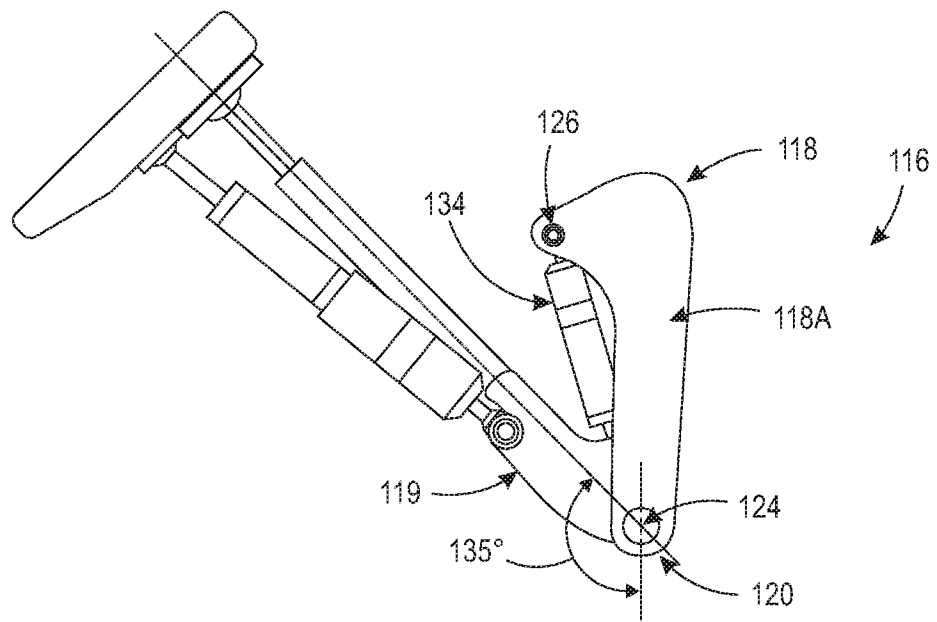


FIG. 6

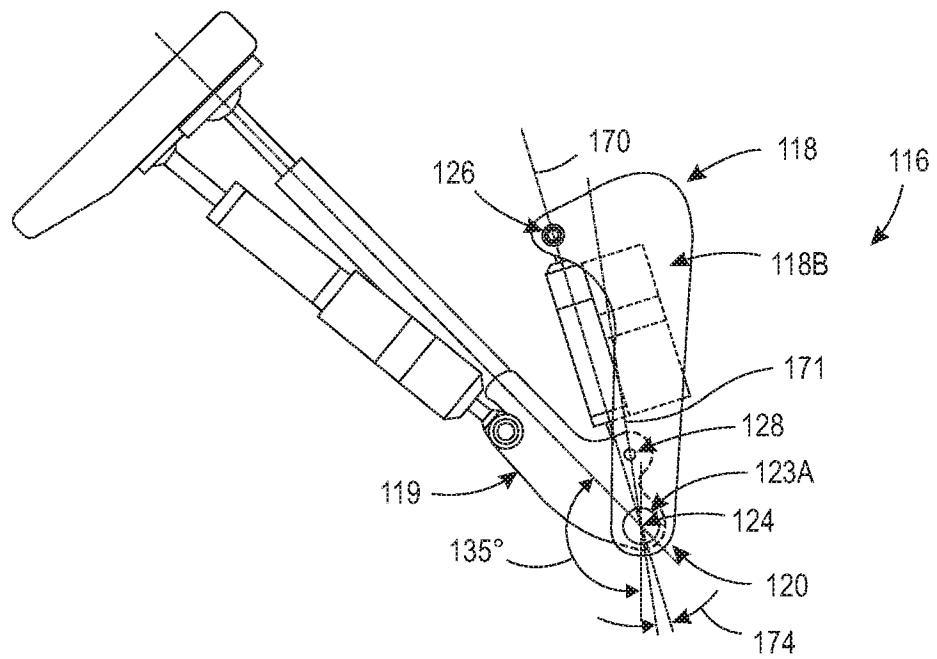


FIG. 7

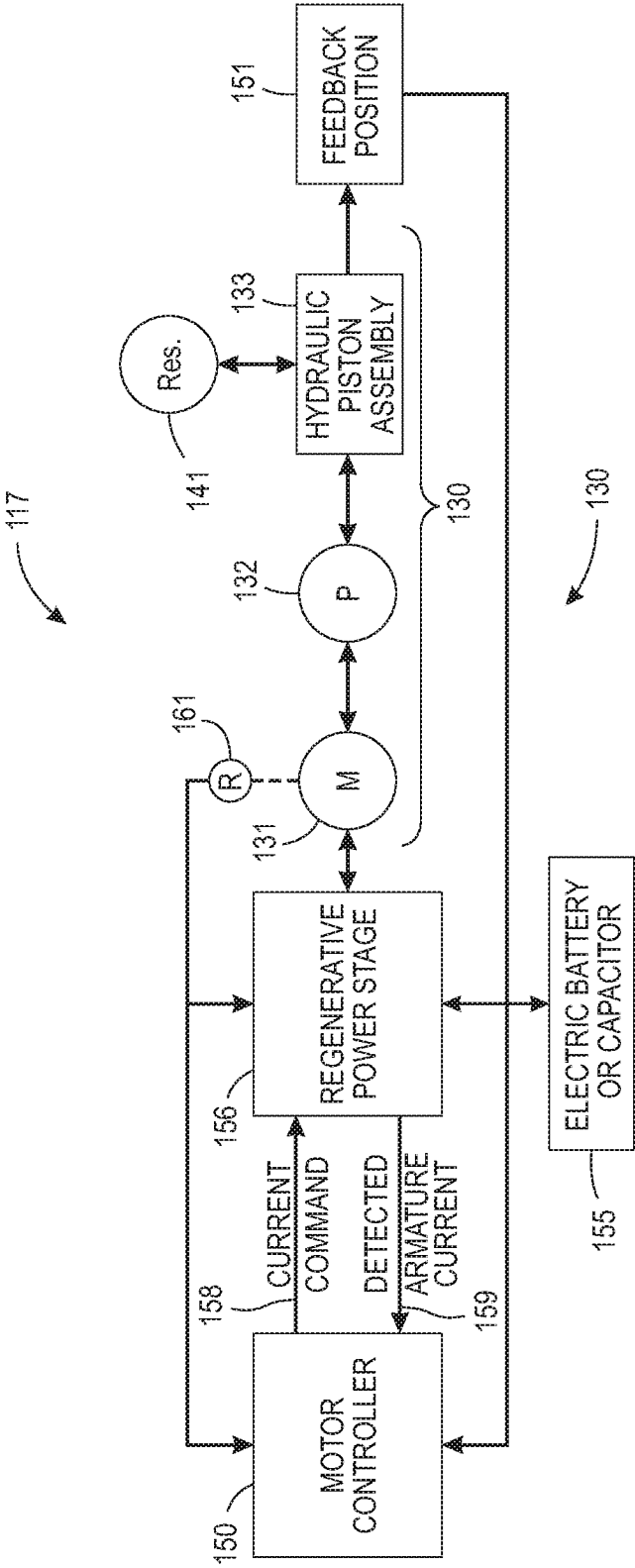


FIG. 8

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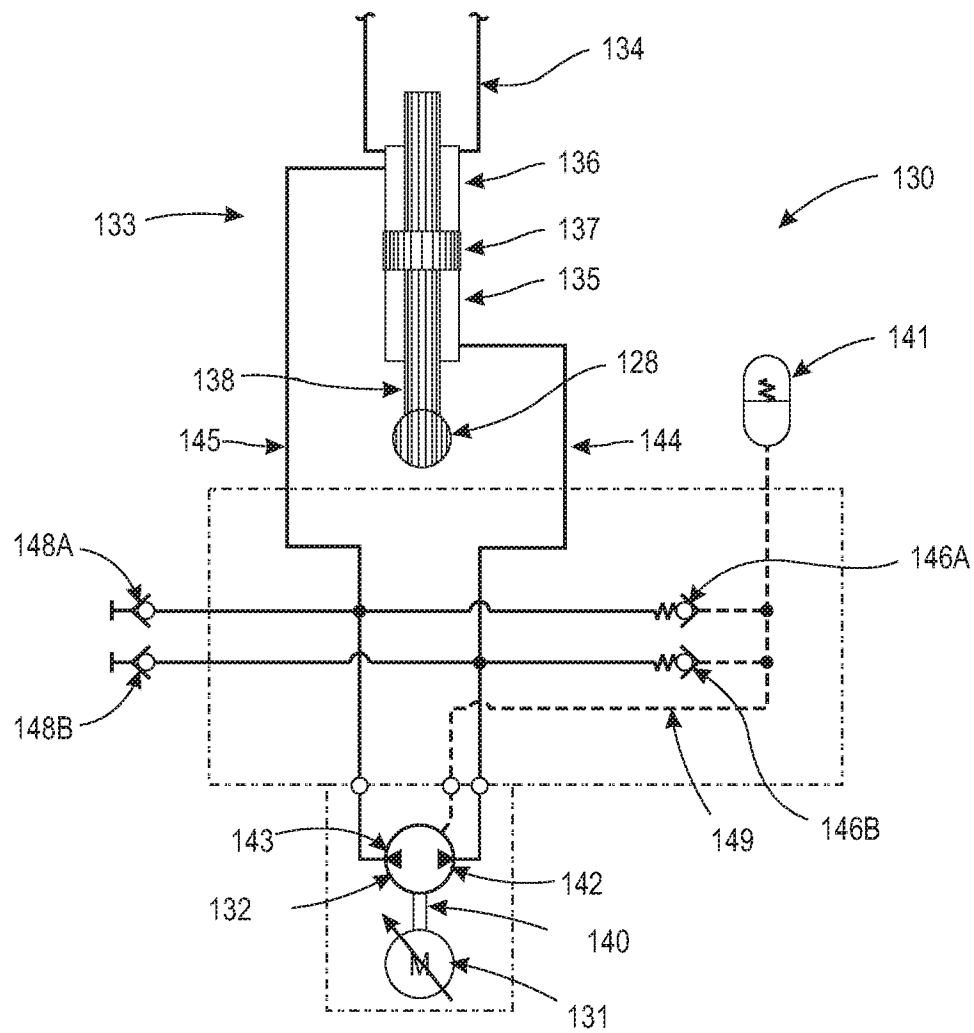


FIG. 9

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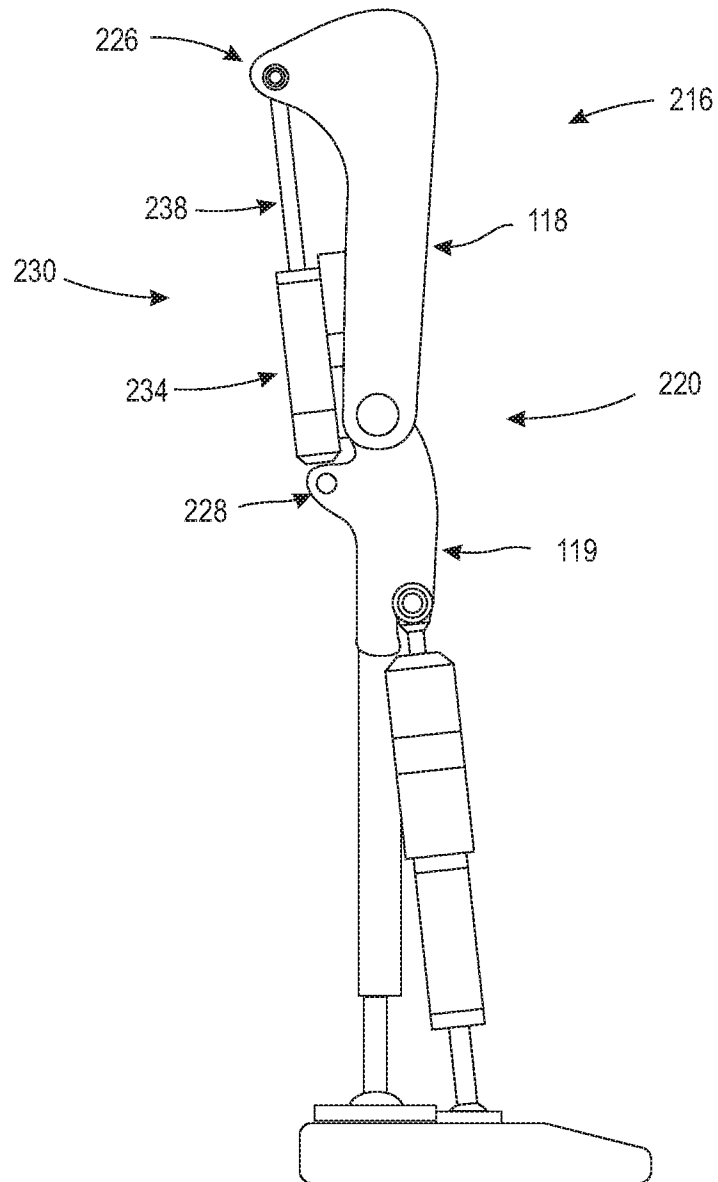


FIG. 10

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2019/066034

A. CLASSIFICATION OF SUBJECT MATTER

INV. B25J9/14 B25J17/00 F15B15/18
ADD.

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 F15D F15B F04B

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)

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C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2013/150980 A1 (SWIFT TIM [US] ET AL) 13 June 2013 (2013-06-13) figures 1-20 paragraph [0060] paragraphs [0064], [0065] paragraphs [0068], [0069] paragraph [0077] paragraph [0096] paragraph [0126] paragraphs [0138], [0139] -----	1-10,13, 14
X	US 9 895 804 B1 (PERKINS ALEXANDER DOUGLAS [US] ET AL) 20 February 2018 (2018-02-20) figures 1,3A column 5, line 6 - line 28 column 7, line 36 - line 42 column 8, line 62 - column 9, line 7 ----- -/--	1,8,11, 12,14



Further documents are listed in the continuation of Box C.



See patent family annex.

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Date of the actual completion of the international search

16 March 2020

Date of mailing of the international search report

26/03/2020

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INTERNATIONAL SEARCH REPORT

International application No
PCT/US2019/066034

C(Continuation). 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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Information on patent family members

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