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(54) **UPPER EXTREMITY EXOSKELETON STRUCTURE AND METHOD**

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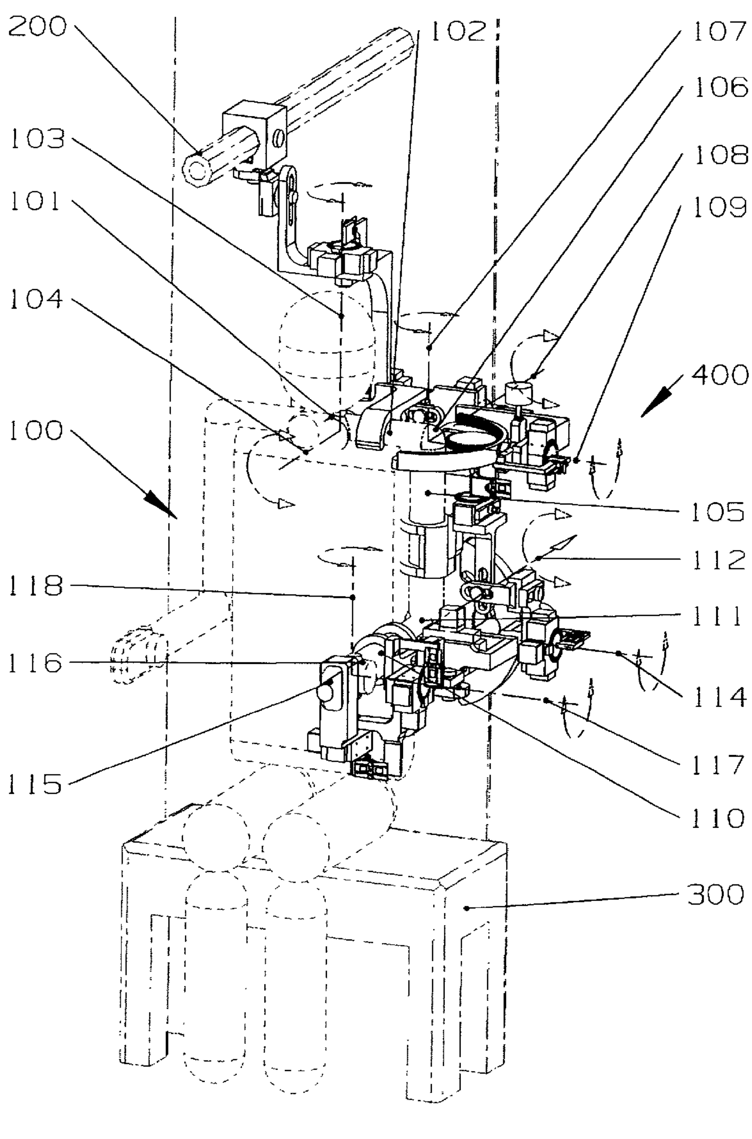
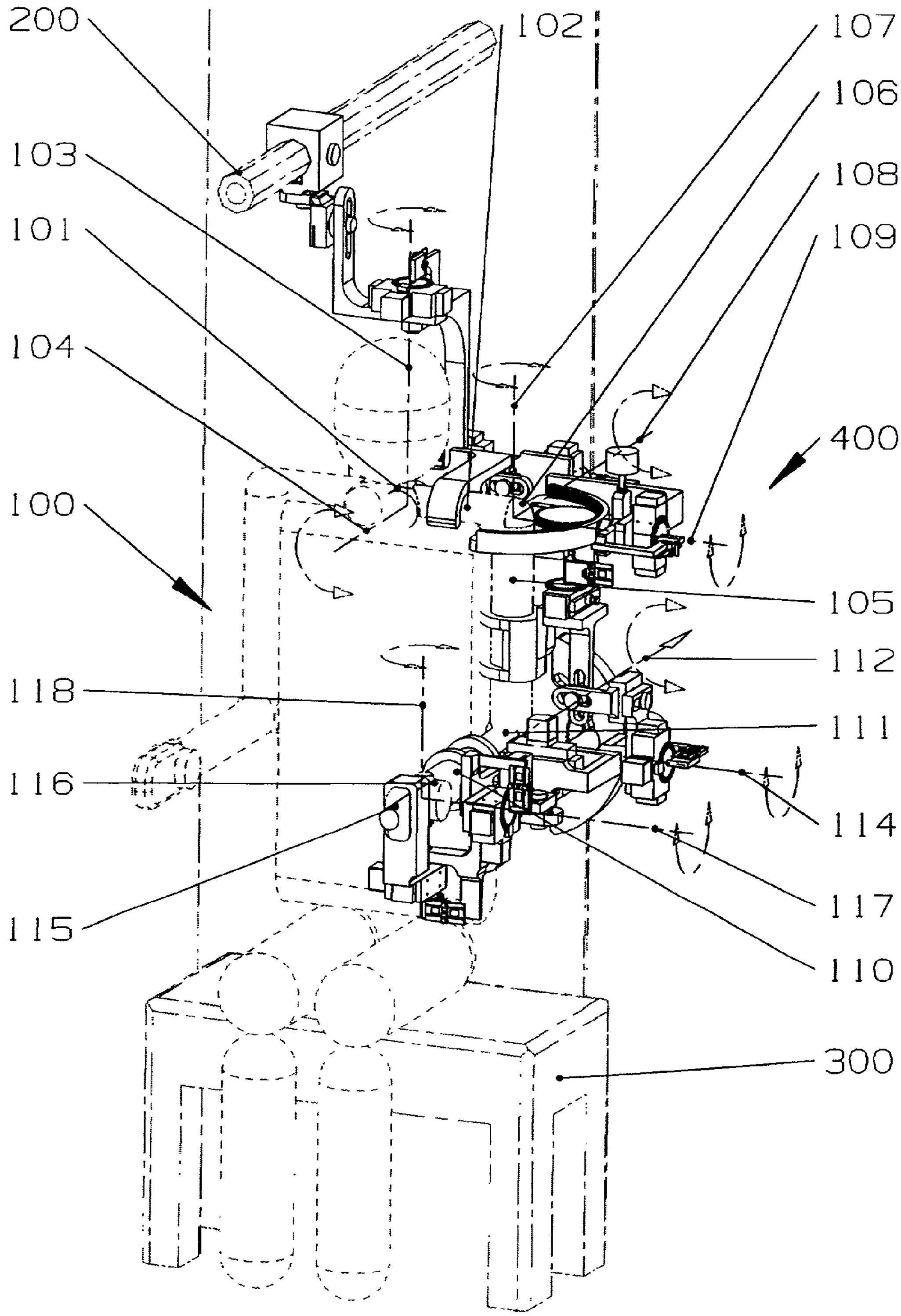
(57) **ABSTRACT**

The adjustable to a user's upper extremity the exoskeleton structure provides testing and exercising of the whole upper extremity in a realistic manner without infringement of a locomotor act and with selective biomechanical information and exercise loading in each anatomical motion direction of every joint simultaneously. The exoskeleton structure comprises jointed means for connection with a user's shoulder-girdle, upperarm, forearm, and hand. Those means include measuring-loading blocks to measure muscle forces and joint angles and to apply a dosed exercise load. All measuring-loading blocks in the exoskeleton structure are identical. The exoskeleton structure is able to provide a realistic and comprehensive information about both a complex locomotor act and a selective mono-planar motion for both isometric and isotonic muscular contractions.




200
102
107
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300

FIG. 1

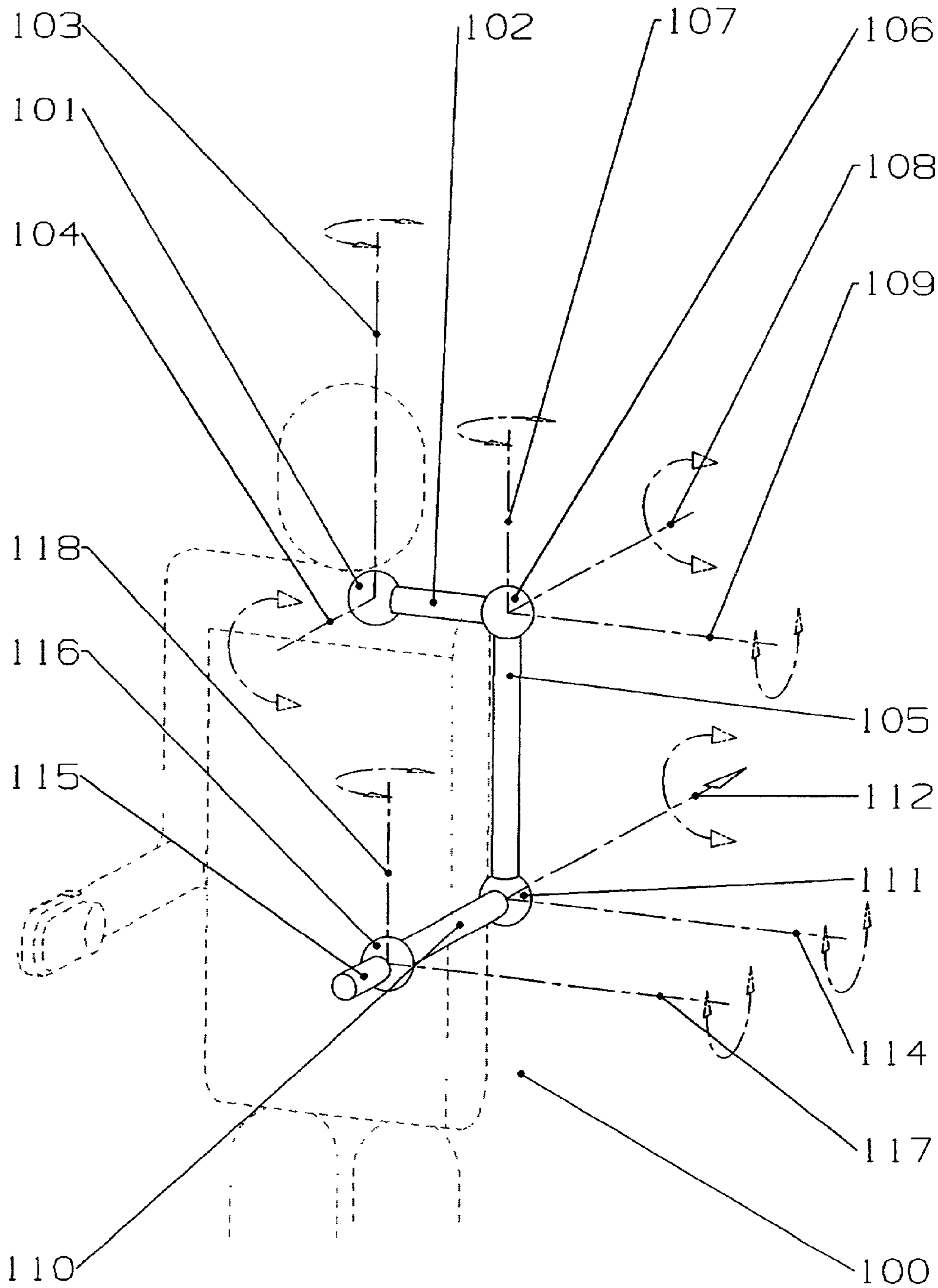
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FIG. 1A

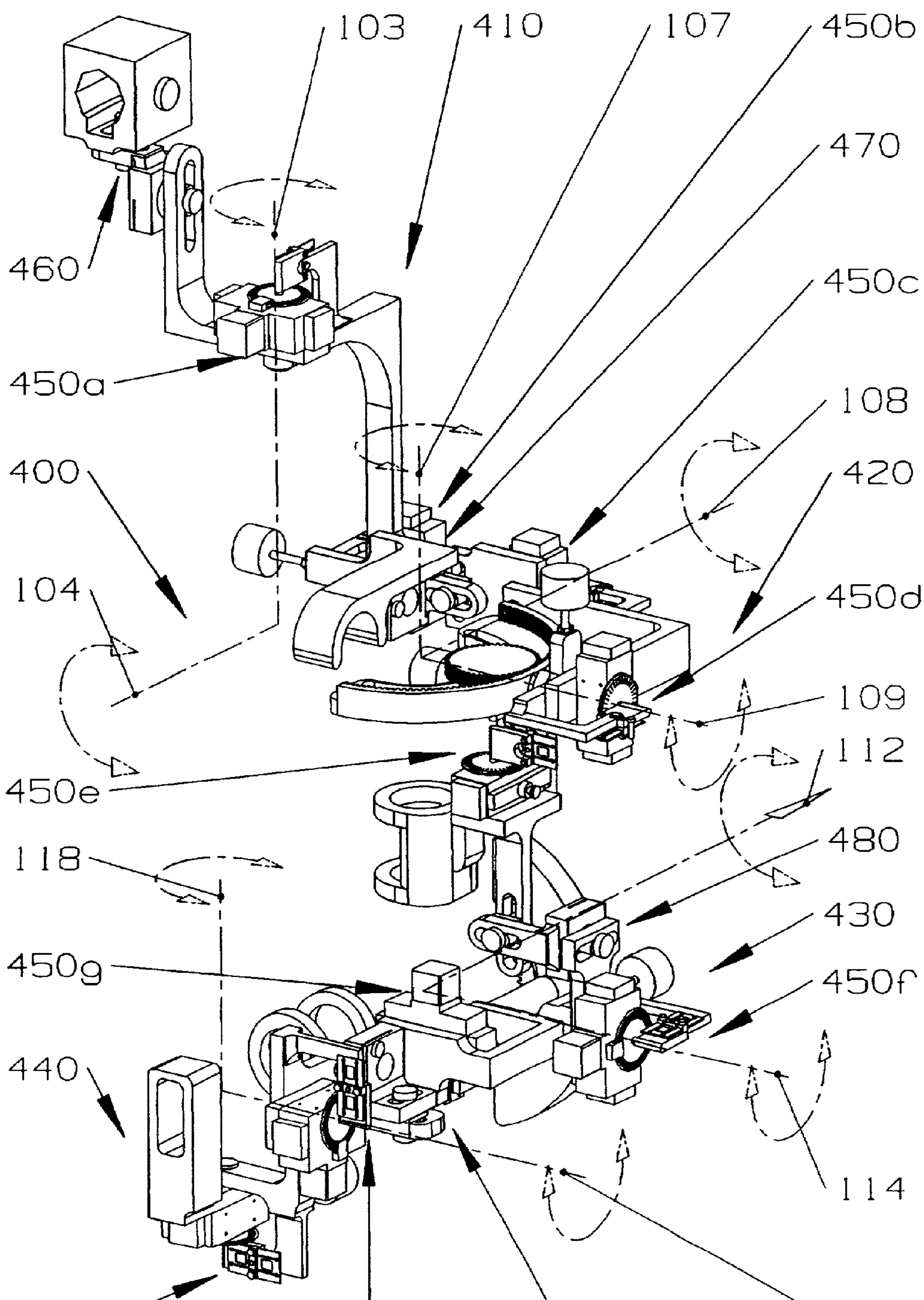

103
410
107
450b
470
450c
460
450a
108
400
420
104
450d
109
450e
112
118
480
430
450g
450f
440
114
450i
450h
490
117

FIG.2

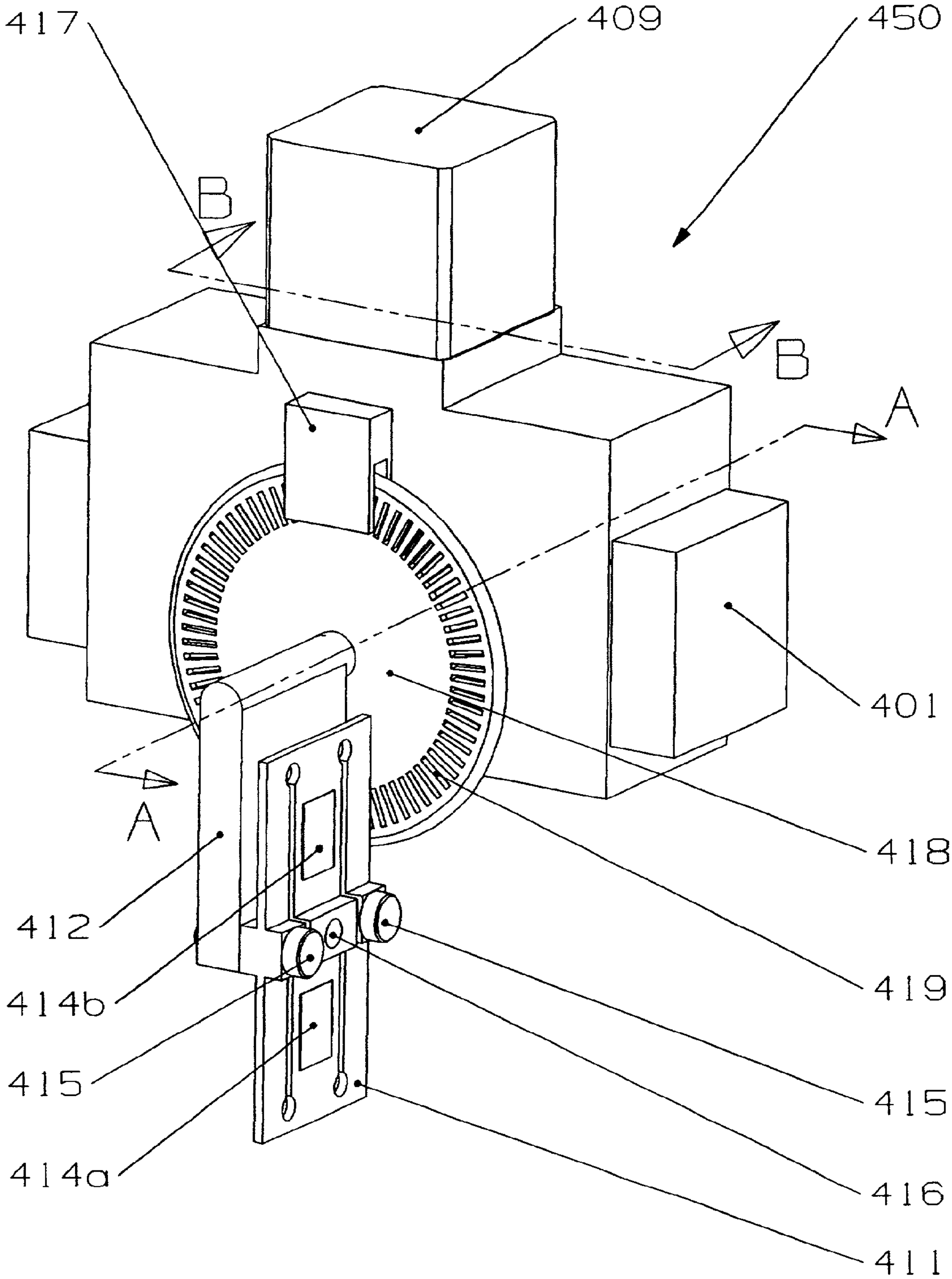
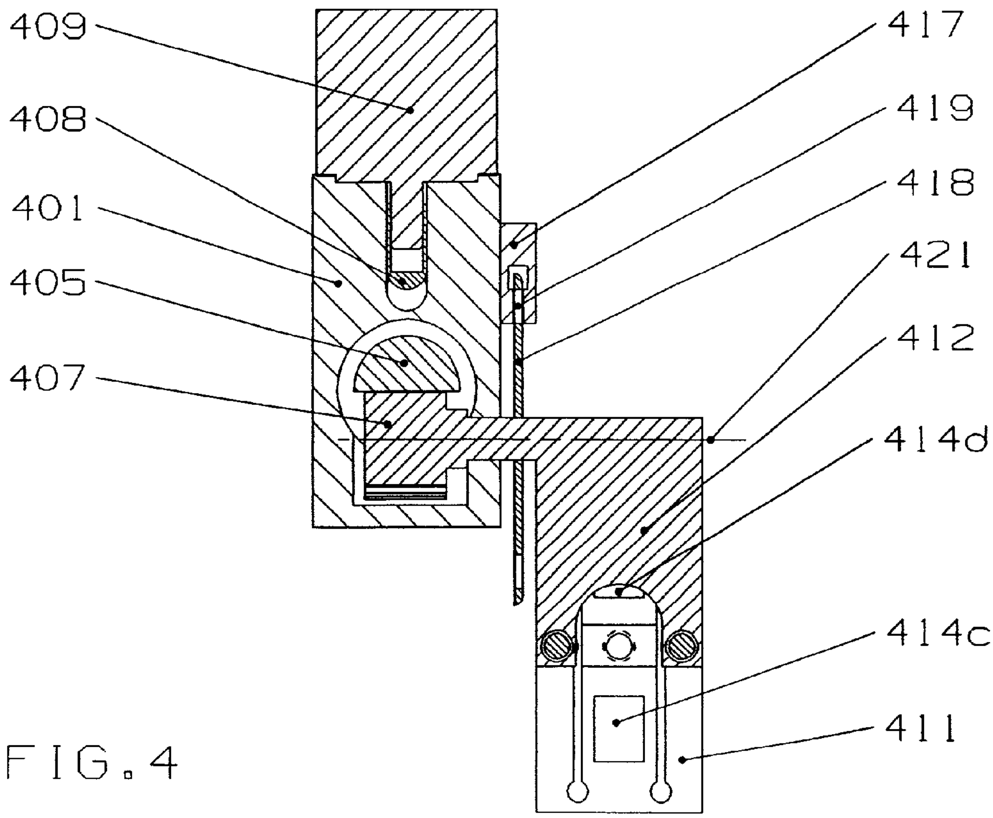


FIG.3


409
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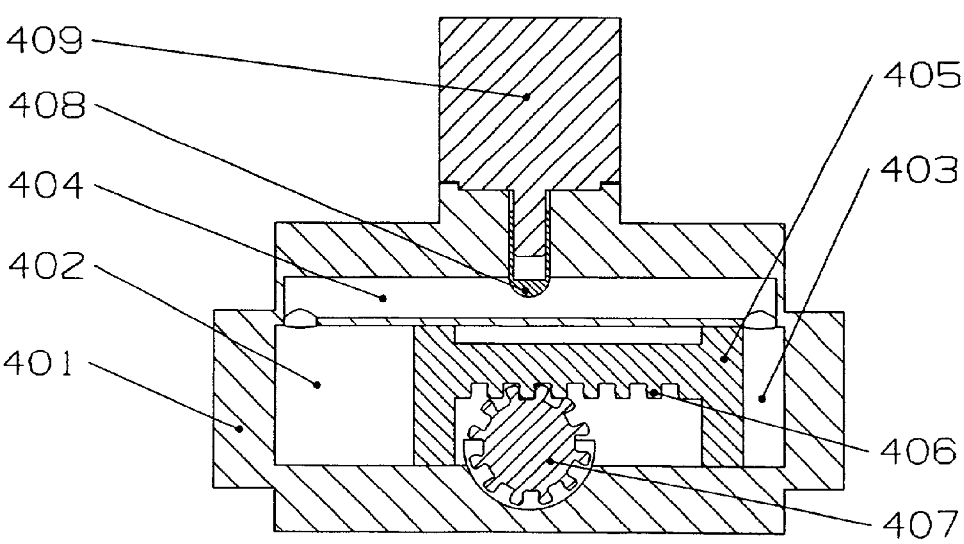
421
412
414d
414c
411

FIG.4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407

FIG.5

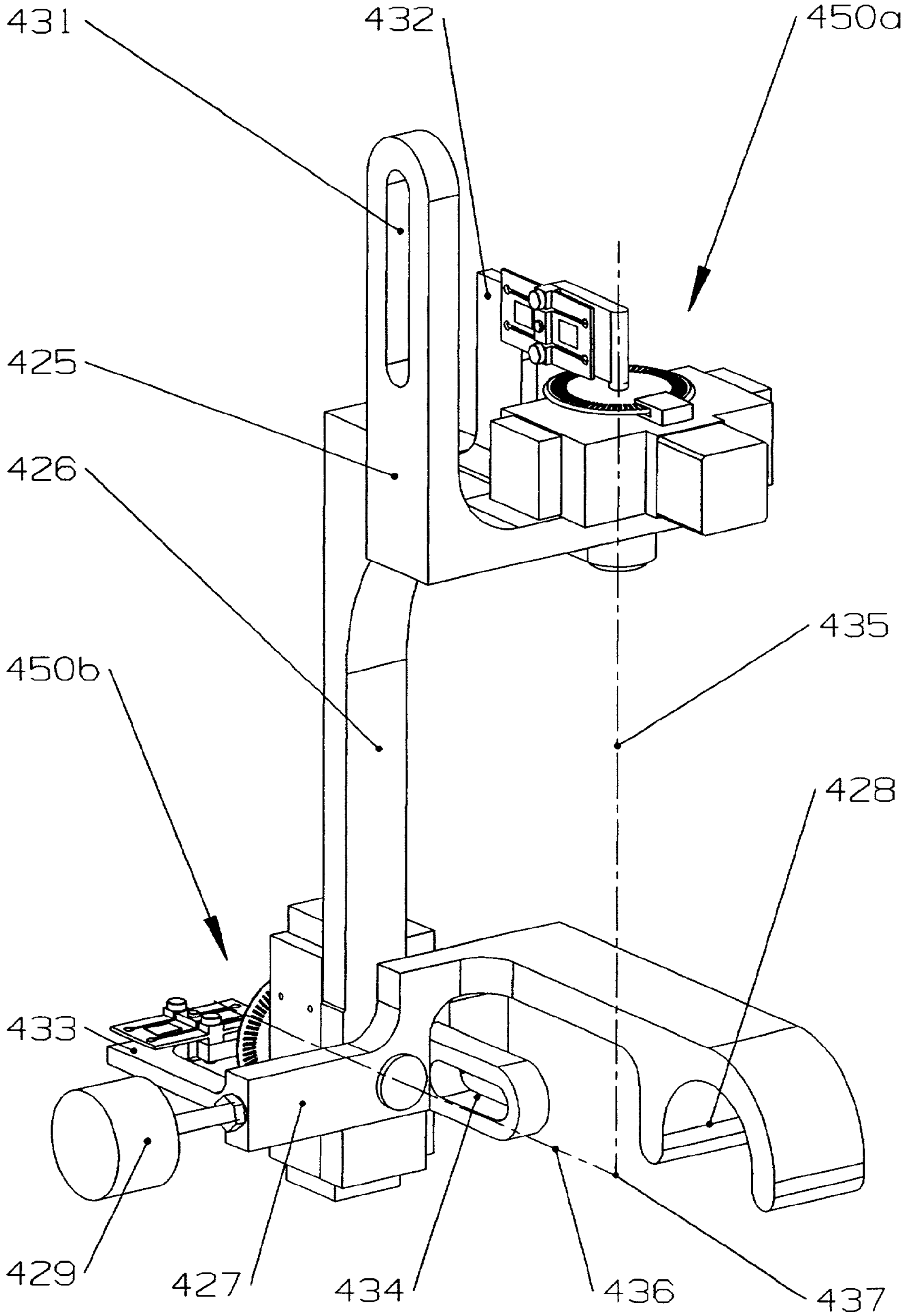
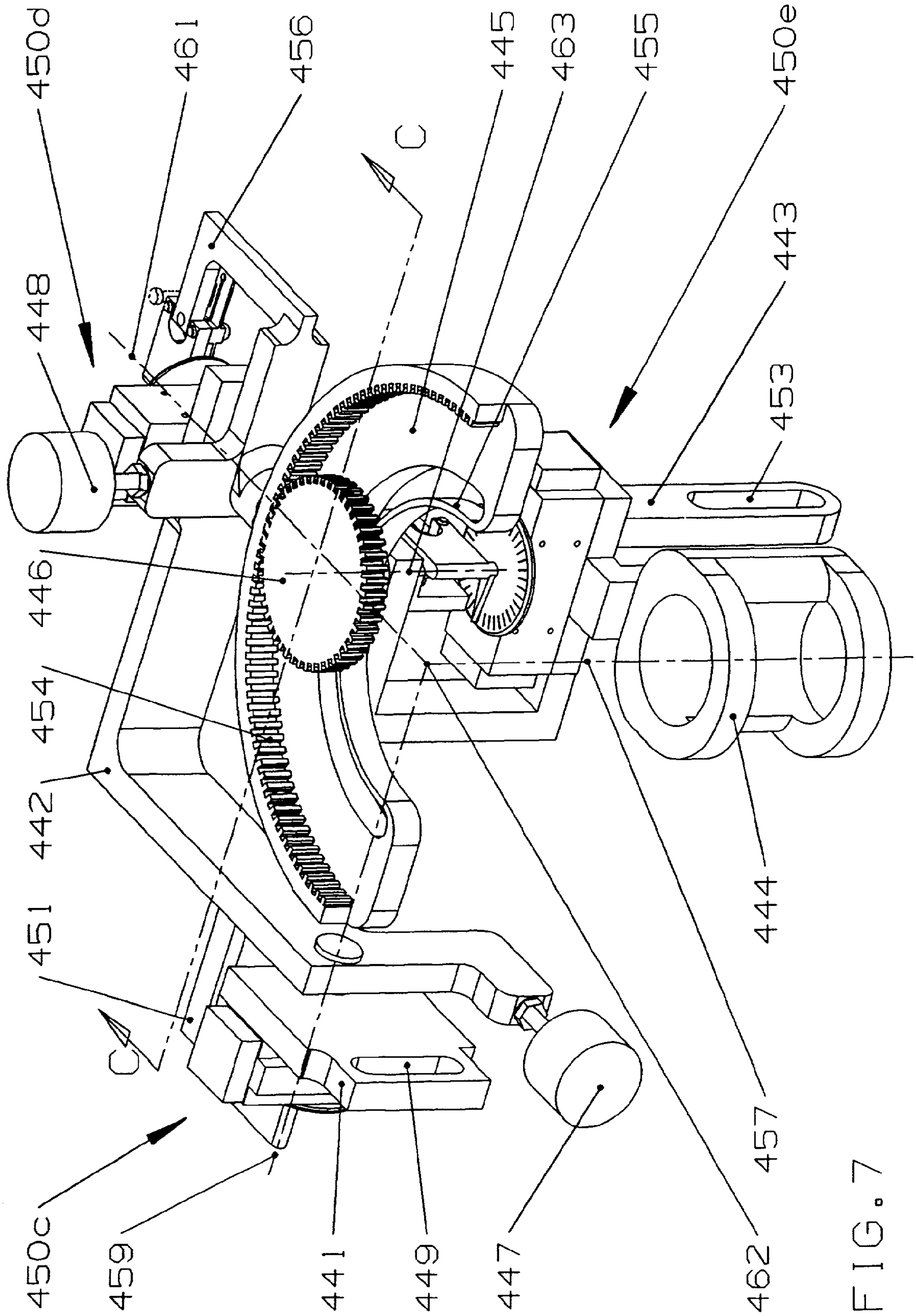


FIG.6


450d
461
456
445
463
455
450e
C
448
443
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441
449
447
462

FIG. 7

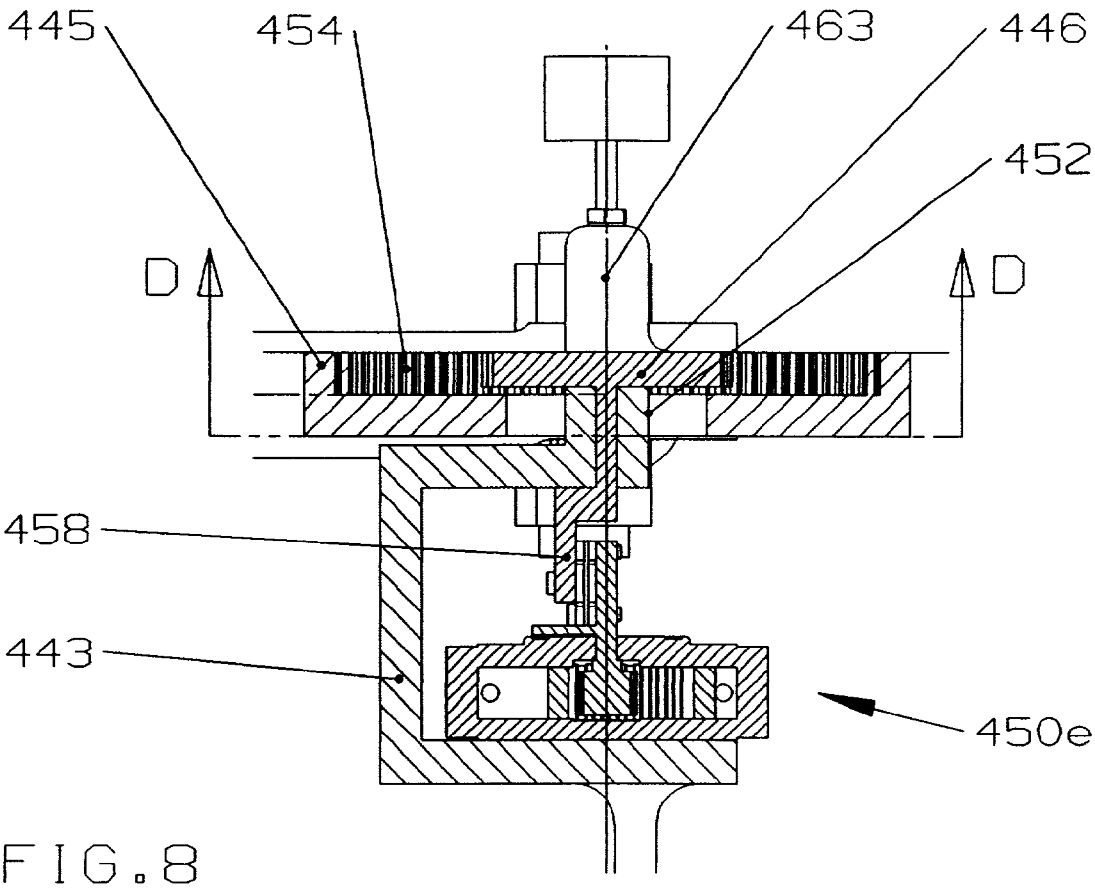


FIG.8

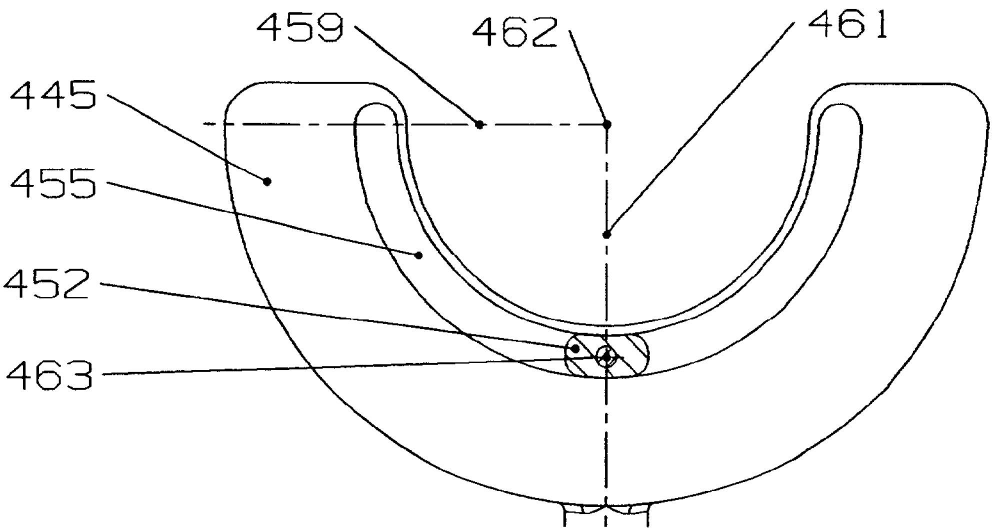
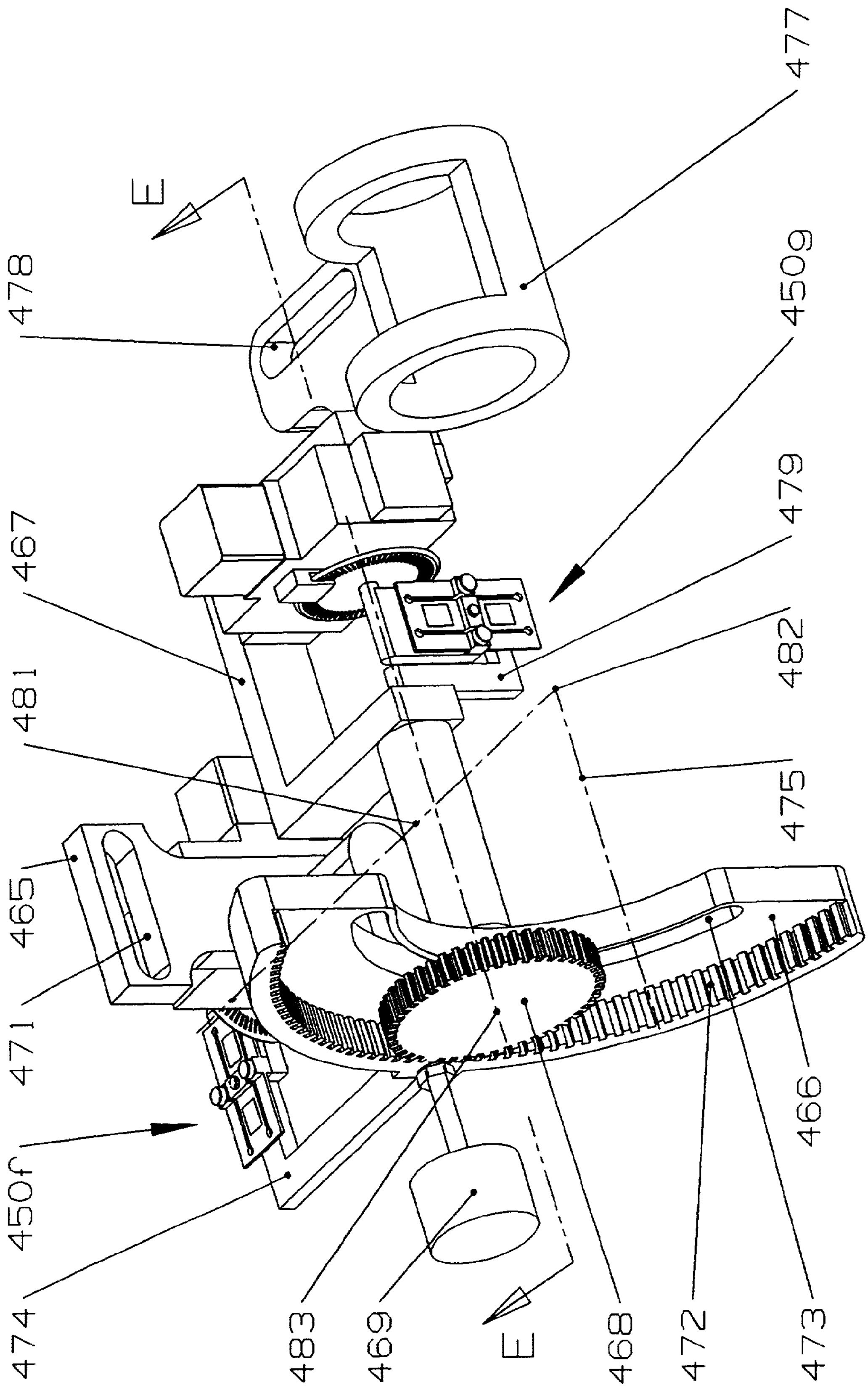


FIG.9


477
E
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450g
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450f
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FIG. 10

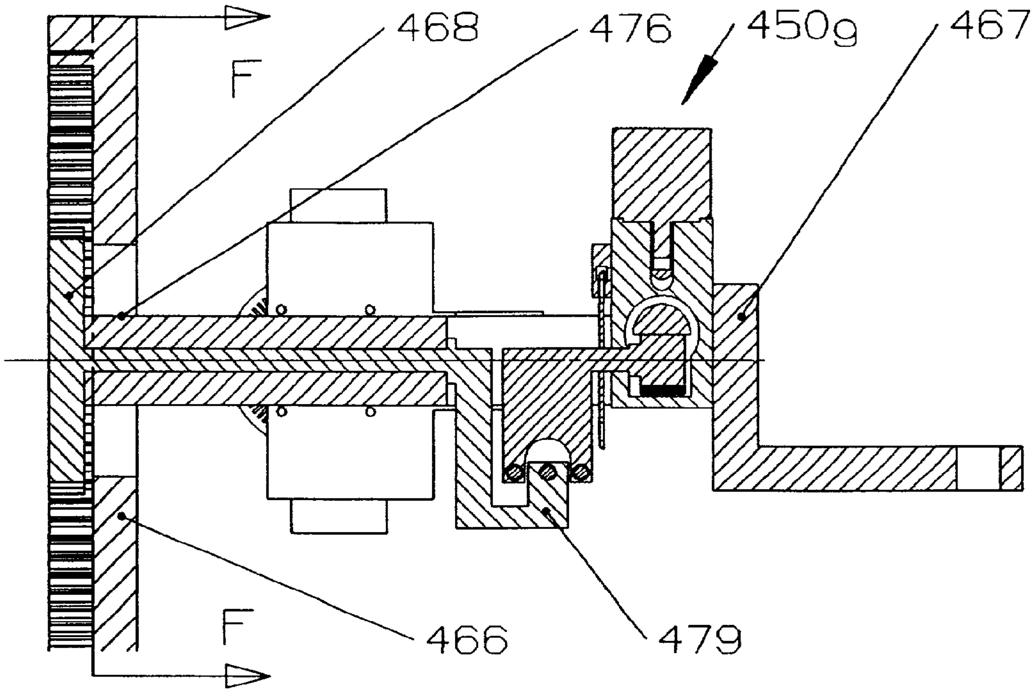


FIG. 11

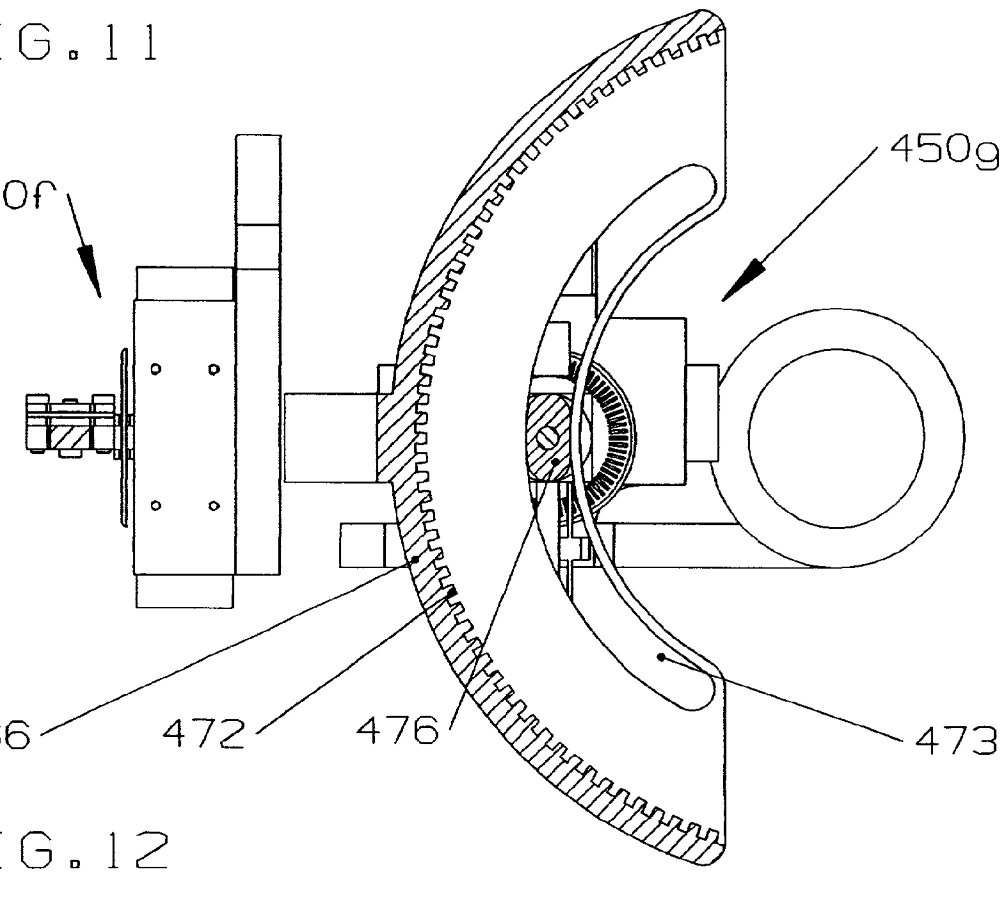


FIG. 12

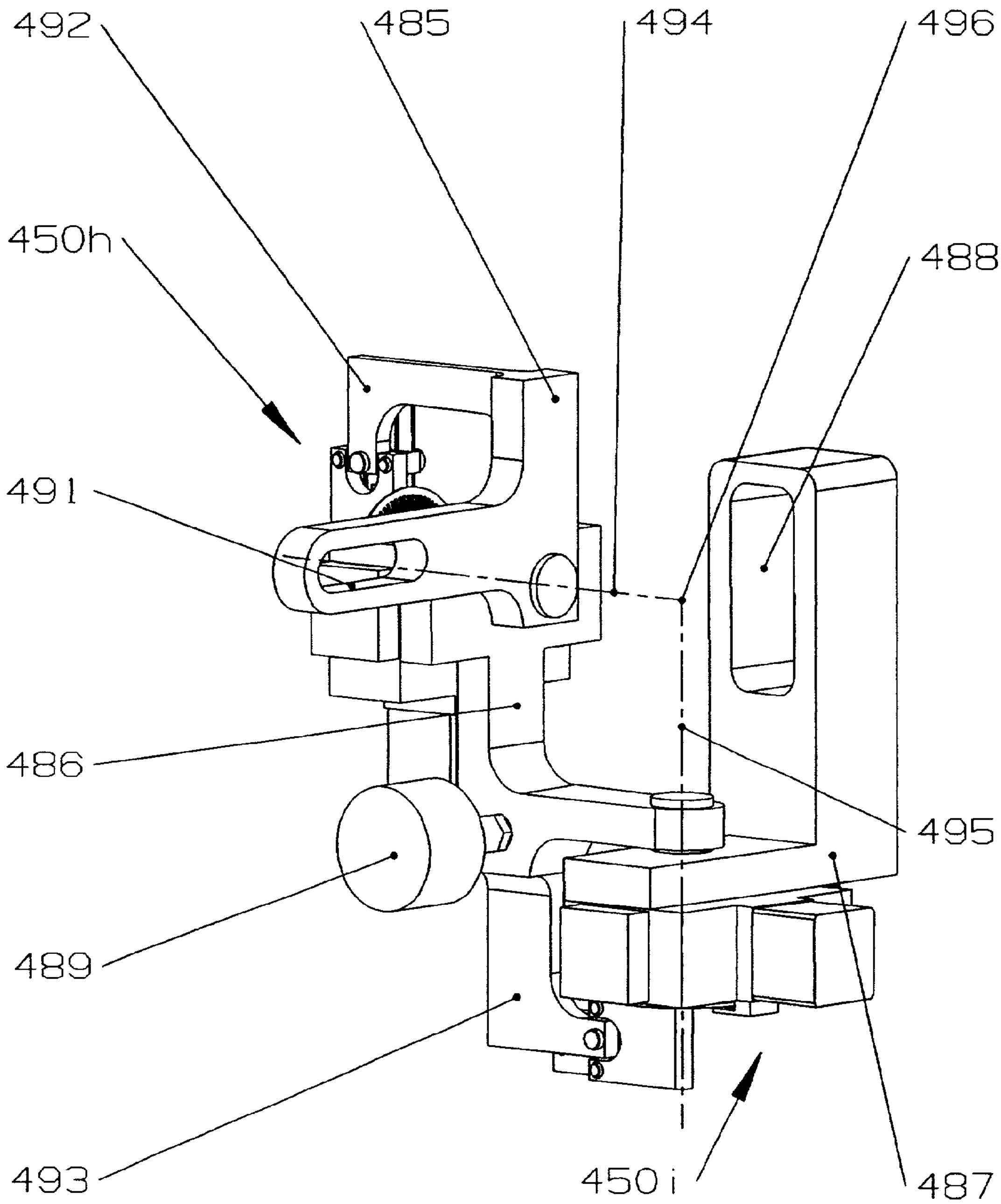
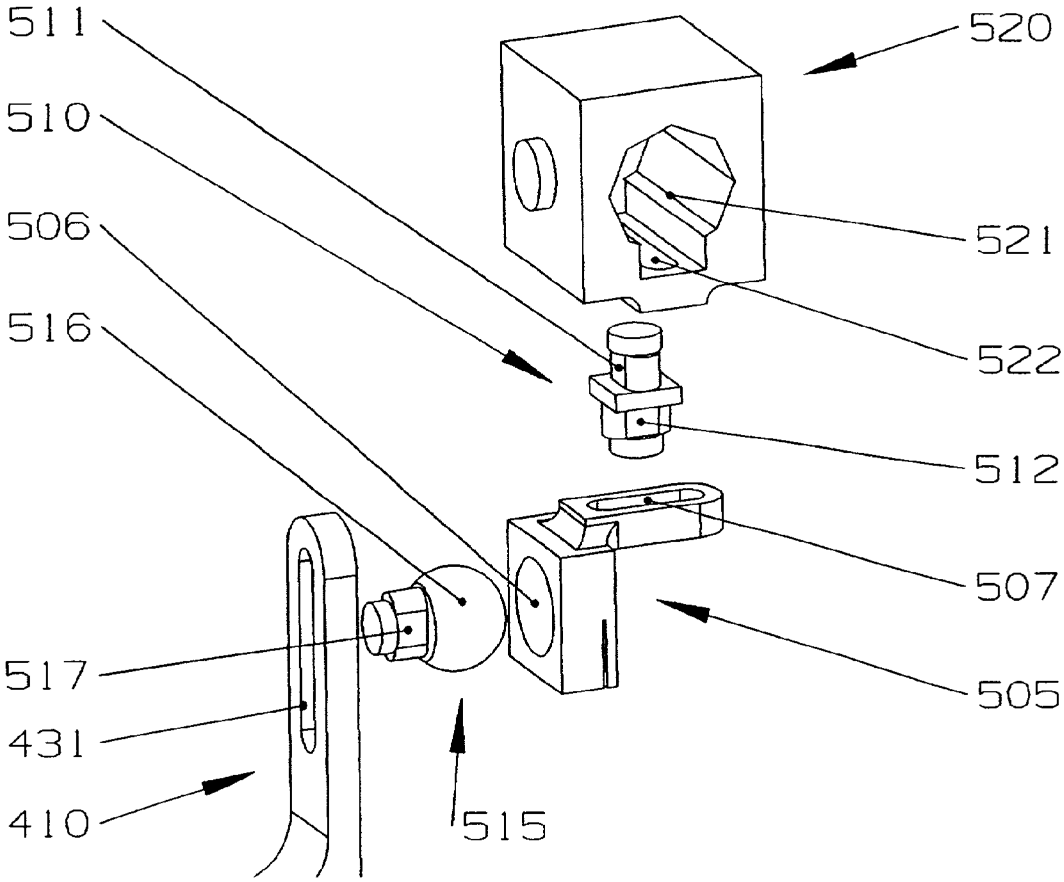


FIG. 13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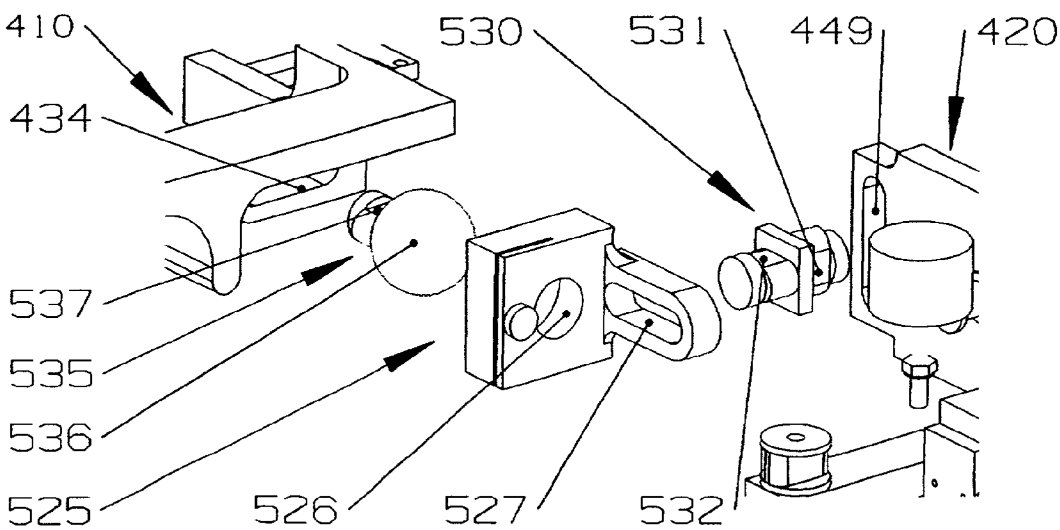
505

FIG. 14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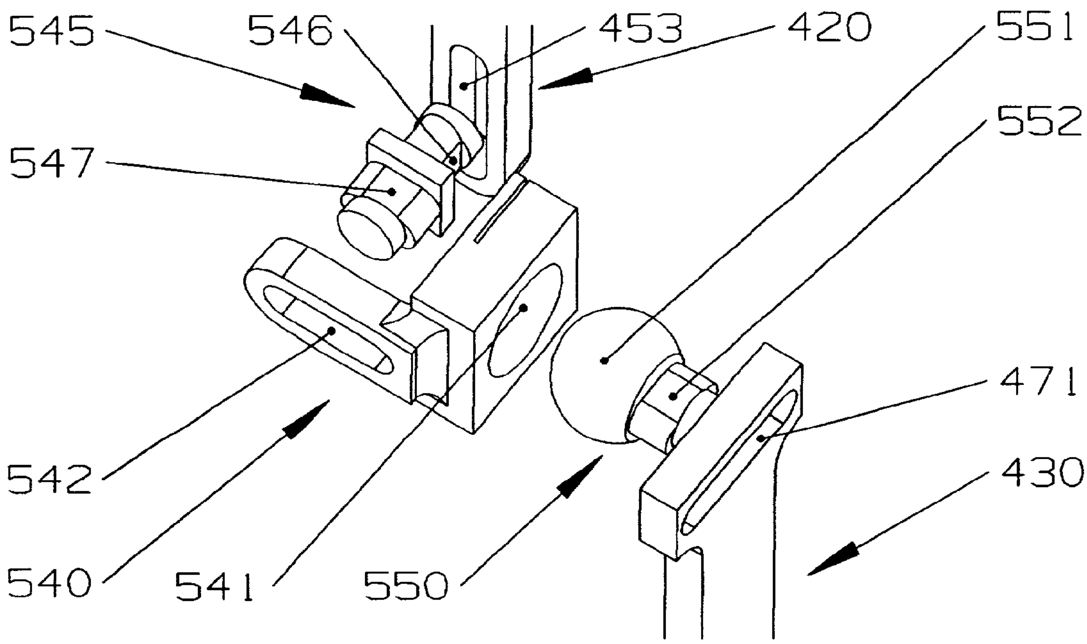
531
449
420

FIG. 15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420
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471
430
542
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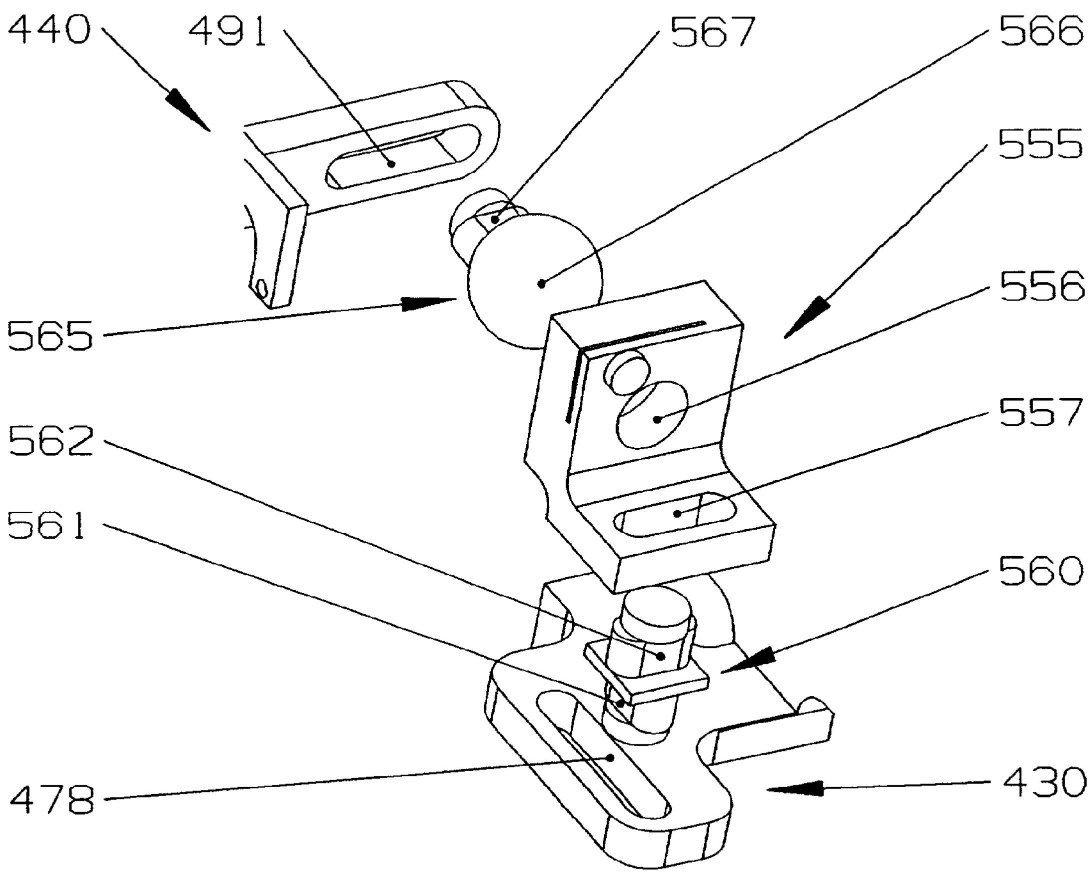
541
550

FIG. 16


440
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566
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561
560
478
430

FIG. 17

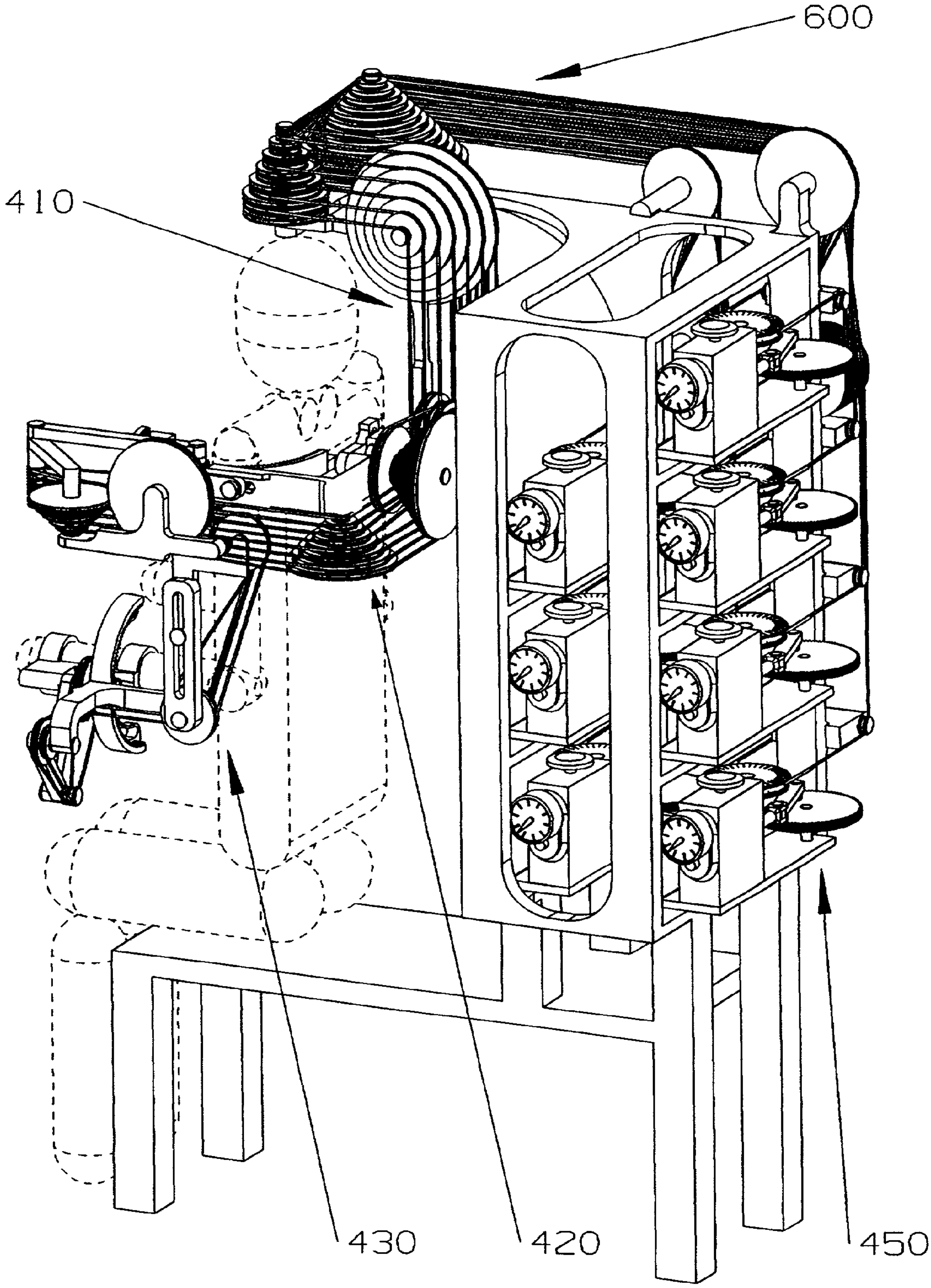

FIG. 18

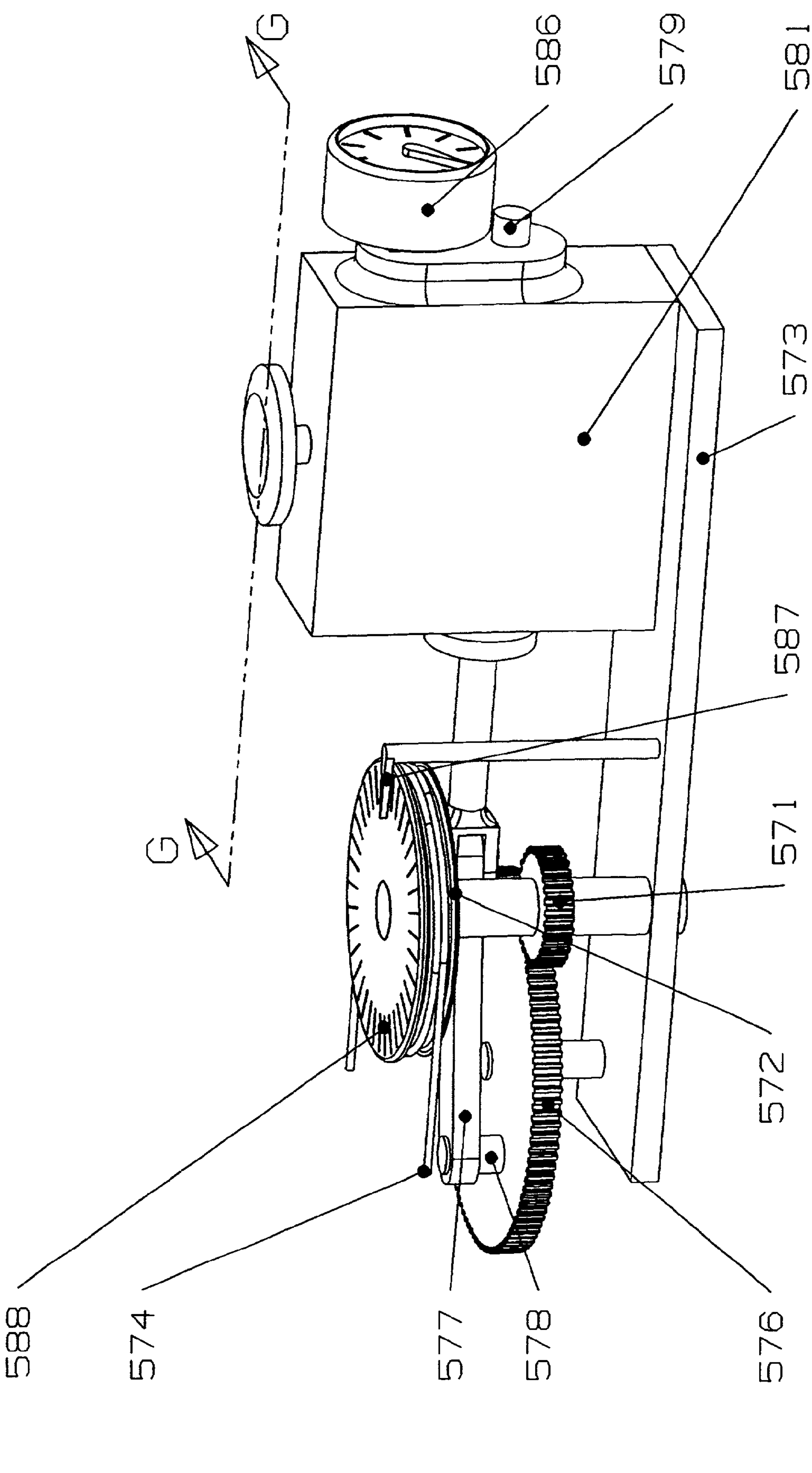

FIG. 19

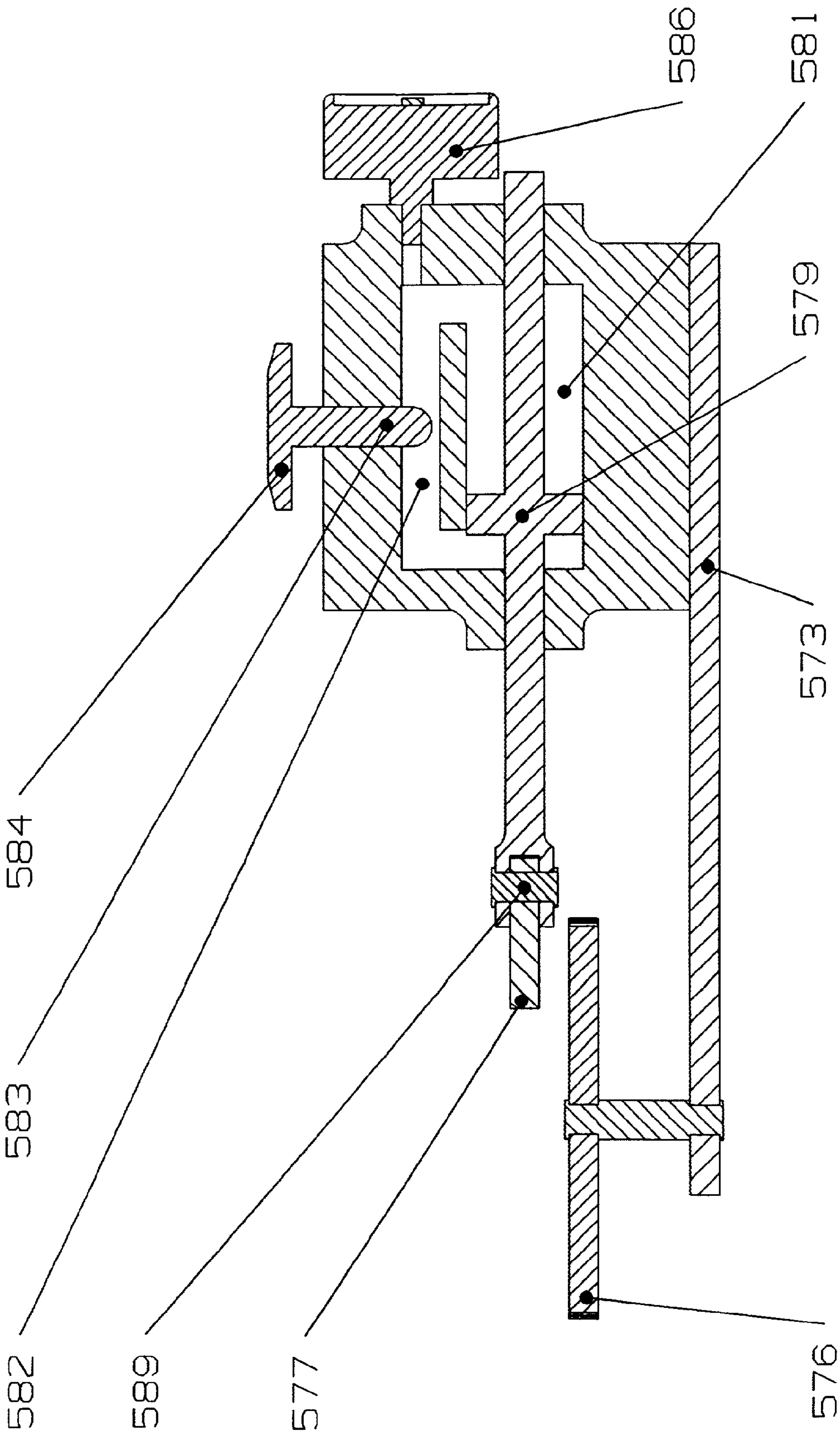

FIG.20

UPPER EXTREMITY EXOSKELETON STRUCTURE AND METHOD

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

[0001] Not applicable

CROSS REFERENCE TO RELATED APPLICATIONS

[0002] Not applicable

REFERENCE TO A MICROFISH APPENDIX

[0003] Not applicable

BACKGROUND OF THE INVENTION

[0004] The present invention relates generally to the equipment and the process for the diagnostic and rehabilitation of a human body locomotor apparatus. More specifically, the present invention relates to an exoskeleton structure to research and exercise the whole upper extremity simultaneously in live multi-joint motion exploring and providing the real data on anatomical torque, forces, and angles in each joint of the extremity.

[0005] A human body upper extremity, schematically shown on **FIG. 1A**, includes four big basic anatomical joints: sternoclavicular, shoulder, elbow and wrist. As shown on **FIG. 1A** a sternoclavicular joint **101** secures a shouldergirdle **102** to a sternum of a human body (a user's body) **100** with two anatomical rotation axes **103** and **104**. An upward-downward motion of the shouldergirdle **102** is provided by its rotation about the axis **104**, and a forward-backward motion of the shouldergirdle **102** is provided by its rotation about the axis **103**. An upper arm **105** is attached to the shouldergirdle **102** by means of a shoulder joint **106** having three anatomical rotation axes **107**, **108**, and **109**. Flexion-extension, abduction-adduction, and rotation motions of the upper arm **105** are provided by rotation of the upper arm **105** about axes **107**, **108**, and **109** respectively. A forearm **110** is attached to the upper arm **105** by an elbow joint **111** having two anatomical rotation axes **112** and **114**. Flexion-extension and pronation-supination motions of the forearm **110** are provided by rotation of the forearm **110** about axes **112** and **114** respectively. A hand **115** is attached to the forearm **110** by a wrist joint **116** having two anatomical rotation axes **117** and **118**. Flexion-extension and abduction-adduction motions of the hand **115** are provided by rotation of the hand **115** about axes **117** and **118** respectively.

[0006] The motion stereotype of an individual is formulated by aggregating all the above mentioned motions. The motion stereotype is a complex procedure of muscle interactions that is characterized by minimal expenditure of a muscle energy and defined by a certain launching sequence of different muscles, and dynamic and kinematics parameters of each joint participating in the motion. In medical science, the motion stereotype is an evidence of the normal functioning of the whole organism in general and the upper extremity in particular. Infringement of the motion stereotype is taking place as a result of the muscle contraction change that is the signal of either a larvate or even a developed pathology (in neurology, for example). In a process of the after-stroke physical rehabilitation, for instance, a patient needs to reproduce a precisely coordinated upper extremity motion under control of the biofeedback signals. For assigning a rehabilitation program to a patient after heart attack, local arm isometric muscular work results are used along with the ECG parameters. For defining functional conditions of the patient, ECG, EEG and EMG methods are usually applied in combination with a biomechanical data of the upper extremity functioning.

[0007] The most important issue in a diagnosis and a therapy is the exact translation of patient's motion into an exercise device. The better the translation process and the chosen exercise pattern, the more correct the diagnostic results and the more effective physical therapy. And as a result, recovery of the patient will take place faster. It is clear that the trustworthiness of testing and exercising results depends on the exact amount of muscle simultaneous work of the upper extremity segments in every anatomical motion direction.

[0008] Methods and equipment for the upper extremity testing and exercising are known. U.S. Pat. No 6,162,190, for example, discloses a method of testing the shouldergirdle-upperarm—forearm kinematically constrained multi-articulated structure with plurality of links, joints and angle position sensors. Axes of the rotation of joints in the structure are coincided with the corresponding anatomical axes of rotation. While the method can be applied for different kinematic tests, it does not include a comprehensive means for exercising and dynamic testing and cannot be used for the diagnosis/rehabilitation programs. An external multi-sectional wireframe attaching to user's body segments for translation of biomechanical parameters into gages and provision an exercise load is usually called an exoskeleton. U.S. Pat. No 6,155,993 discloses an exoskeleton structure comprises a linkage for rotation of two joints in an upper extremity, loading means, angular position sensors, and a harness means attaching the linkage to distal segments of the upper extremity. Linkage axes of articulation in this teaching are parallel, and, thus, the device can be employed only for mono-planar motion of two joints. As well, loading means can not be used independently: a loading dose on one segment depends on the loading dose on another segment. U.S. Pat. No 5,755,645 discloses an exercise apparatus including a multi-link arm with six degree of freedom motion, resistance mechanisms, force sensors, and a harness means. The structure is capable of exercising the complicated functional motions such as throwing a ball or swinging a baseball, but spatial position of joints of the upper extremity cannot be defined, amount of an exercise load is exerted to just one point, and the exercise load cannot be adjusted selectively for each joint of the user's extremity.

[0009] The main object of the present invention is to develop a structure and a method that can provide testing and exercising of the whole upper extremity in a realistic manner without an infringement of a user's body locomotor structure, but with a selective biomechanical information and exercise loading for each anatomical motion direction in every joint simultaneously.

[0010] Another object of the present invention is to develop a structure to test and exercise both a complex locomotor act and a simple mono-planar motion for both isometric and isotonic muscular contractions.

[0011] Another object of the present invention is to develop a structure for determining dynamometry and goniometry parameters selectively in each anatomical motion direction for every joint of the user's upper extremity during a predetermined locomotor act.

[0012] Another object of the present invention is to develop a structure to adjust the resistance amount of test/exercise selectively for each anatomical motion direction in every joint of the user's upper extremity.

[0013] Another object of the present invention is to develop a modality means having the possibility of reconfiguration of the exoskeleton structure in accordance with predetermined locomotor act, number of links participating in that act, and user's anatomical link size.

BRIEF SUMMARY OF THE INVENTION

[0014] The present invention relates to an exoskeleton structure and a method for testing and exercising of the user's body upper extremity with selectively dosed load and biomechanical measurement of each segment in the upper extremity.

[0015] The exoskeleton structure comprises four functional modules: a sternoclavicular, a shoulder, an elbow, and a wrist. Those modules include measuring-loading blocks that are identical, links, and revolute joints. Every measuring-loading block comprises a resistance device to adjust a load for the predetermined exercise motion, a dynamometric device to determine the muscle force, and a goniometric device to measure the joint angle. The shoulder module is connected to the sternoclavicular module, the elbow module is connected to the shoulder module, and the wrist module is connected to the elbow module. In operation the sternoclavicular module is secured to a stationary object. The exoskeleton structure also includes means for connecting modules and for adjustment the distances between joints in accordance with a user's upper extremity link size.

[0016] The method for the upper extremity test and exercise comprising a disposition of the exoskeleton structure on the upper extremity wherein all axes of revolute joints in the exoskeleton structure coincide with corresponding axes of anatomical joints of the upper extremity, an adjustment of an exercise resistance for a predetermined exercise motion, and a measurement of a force and an angular displacement of each of the above segments of the upper extremity.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS

[0017] The following detailed description of the present invention will be better understood with reference to the accompanying drawings, wherein:

[0018] **FIG. 1A** is a biomechanical schematic view of the upper extremity of a human body;

[0019] **FIG. 1** is a pictorial view of the exoskeleton structure in accordance with the present invention that is superimposed on the upper extremity of a user sitting on a bench (shown by dotted lines);

[0020] **FIG. 2** is a pictorial view of the jointed modules of the exoskeleton structure to **FIG. 1** with superimposed anatomical axes shown on **FIGS. 1A and 1**;

[0021] **FIG. 3** is a pictorial view of a measuring-loading block of the exoskeleton structure to **FIG. 2**.

[0022] **FIG. 4** is a cross section view along line A-A on **FIG. 3**;

[0023] **FIG. 5** is a cross section view along line B-B on **FIG. 3**;

[0024] **FIG. 6** is a pictorial view of the sternoclavicular module of the exoskeleton structure to **FIG. 2**;

[0025] **FIG. 7** is a pictorial view of the shoulder module of the exoskeleton structure to **FIG. 2**;

[0026] **FIG. 8** is a cross section view of the shoulder module along line C-C on **FIG. 7**;

[0027] **FIG. 9** is a cross section view of the shoulder module along line D-D on **FIG. 8**;

[0028] **FIG. 10** is a pictorial view of the elbow module of the exoskeleton structure to **FIG. 2**;

[0029] **FIG. 11** is a cross section view of the elbow module along line E-E on **FIG. 10**;

[0030] **FIG. 12** is a cross section view of the elbow module along line F-F on **FIG. 11**;

[0031] **FIG. 13** is a pictorial view of the wrist module of the exoskeleton structure to **FIG. 2**;

[0032] **FIG. 14** is an exploded pictorial view of the sternoclavicular coupling to **FIG. 2**;

[0033] **FIG. 15** is an exploded pictorial view of the shoulder coupling to **FIG. 2**;

[0034] **FIG. 16** is an exploded pictorial view of the elbow coupling to **FIG. 2**;

[0035] **FIG. 17** is an exploded pictorial view of the wrist coupling to **FIG. 2**;

[0036] **FIG. 18** is a pictorial view of another embodiment of the exoskeleton structure in accordance with the present invention;

[0037] **FIG. 19** is a pictorial view of another embodiment of the measuring-loading block in the exoskeleton structure to **FIG. 18**;

[0038] **FIG. 20** is a cross section view of the measuring-loading block along line G-G to **FIG. 19**.

DETAILED DESCRIPTION OF THE INVENTION

[0039] Referring to **FIG. 1**, an exoskeleton structure (ES) **400** is secured to a stationary object, for example, to a wall mounted polygon beam **200**, and attached to the left upper extremity of the user's body **100** located in sitting position on a bench **300**. The ES **400** can also be attached to the right upper extremity if required.

[0040] Referring to **FIG. 2**, the ES **400** comprises a sternoclavicular module **410** (see also **FIG. 6**), a shoulder module **420** (see also **FIGS. 7, 8** and **9**), an elbow module **430** (see also **FIGS. 10, 11,** and **12**), and a wrist module **440** (see also **FIG. 13**). The sternoclavicular module **410** is a two-degree of freedom mechanism having two measuring-loading blocks **450***a* and **450***b* (see also **FIGS. 3, 4,** and **5**). The shoulder module **420** is a three-degree of freedom mechanism having three measuring-loading blocks **450***c*, **450***d* and **450***e*. The elbow module **430** is a two-degree of freedom mechanism having two measuring-loading blocks **450***f* and **450***g*. The wrist module **440** is a two-degree of freedom mechanism having two measuring-loading blocks **450***h* and **450***i*. In operation, the sternoclavicular module **410** should be secured to a stationary object by means of a sternoclavicular coupling **460**, for example, to the polygon wall-mounted beam **200** (see also **FIG. 14**). The shoulder module **420** is connected to the sternoclavicular module **410** by a shoulder coupling **470** (see also **FIG. 15**). The elbow module **430** is connected to the shoulder module **420** by an elbow coupling **480** (see also **FIG. 16**). The wrist module **440** is connected to the elbow module **430** by a wrist coupling **490** (see also **FIG. 17**).

[**0041**] All measuring-loading blocks (MLB) **450***a*-**450***i* are identical. They are shown on **FIGS. 3, 4,** and **5** generally as **450**, and enlarged for clarity. Every MLB comprises a resistance device to adjust the testing/exercising load, a dynamometric device to determine the muscle force, and a goniometric device to measure the joint angle. The resistance device includes a housing **401** having hydraulic chambers **402** and **403** connected by channel **404**, a piston **405** with a gear rack **406**, and a gear shaft **407**. The gear shaft **407** is engaged with the gear rack **406** and installed in the housing **401** wherein it can be rotated. The piston **405** can be moved inside the housing **401** in such a way that chambers **402** and **403** always stay hydraulically connected with a channel **404**. The chambers **402** and **403** and the channel **404** are filled up with the incompressible fluid. The cross-section area of the channel **404** can be adjusted by a valve **408** that can be activated by a stepper motor **409** electrically connected to a computer system (not shown). The smaller the cross-section area of the channel **404** the higher resistance to move the piston **405**. The dynamometric device includes an elastic element **411** having very small elastic deformation, and support **412** secured to the gear shaft **407**. The dynamometric device also includes four strain gages **414***a*-**414***d* that are affixed to the elastic element **411**. Gages **414***a*-**414***d* are electrically connected in a way to form a Wheatstone bridge circuit (not shown) providing an electrical signal proportional to the elastic element **411** deformation. Distal center parts of the elastic element **411** are mounted to the support **412** by screws **415** An inner center part of the elastic element **411** has a hole **416** for connection with the modules **410, 420, 430,** and **440**. The goniometric device involves an index indicator **417** (for example a LEO type) secured to the housing **411** and electrically connected to the computer system (not shown). This device also includes a disk **418** with sircumferentially located slits **419**. The disk **419** is secured to the gear shaft **407**. The gear shaft **407**, the support **412**, and the disk **418** have a common rotation axis **421**. In operation, the testing/exercising load applies to the inner central part of the elastic element **411**. The elastic element **411** together with the elastic element support **412**, the gear shaft **407**, and the disk **418** can be rotated about the axis **421** overcoming the resistance force against a motion of the piston **405** which is defined by the valve **408**. The computer system reads data from the strain gages **414***a*-**414***d* and the indicator **417**.

[**0042**] Referring to **FIG. 6**, the sternoclavicular module **410** consists of two MLBs **450***a* and **450***b*, a first sternoclavicular brace **425**, a sternoclavicular bracket **426**, a second sternoclavicular brace **427** with a shouldergirdle harness **428**, and a sternoclavicular counter weight **429** installed on the second sternoclavicular brace **427** to balance the force of gravitation. The first sternoclavicular brace **425** has a first sternoclavicular slot **431** to secure the sternoclavicular module **410** to a stationary object, for example, the wall-mounted beam **200** by means of the sternoclavicular coupling **460**. The sternoclavicular bracket **426** has a first sternoclavicular extension **432**. The second sternoclavicular brace **427** has a second sternoclavicular extension **433** and a second sternoclavicular slot **434** to secure the sternoclavicular module **410** to the shoulder module **420** by means of the shoulder coupling **470**. The first sternoclavicular brace **425** and the second sternoclavicular brace **427** are mounted on the sternoclavicular bracket **426** and can be rotated around a first sternoclavicular axis **435** and a second sternoclavicular axis **436** respectively. The first sternoclavicular axis **435** intersects the second sternoclavicular axis **436** at the 90-degree angle in a sternoclavicular point **437**. The housing **401** of the MLB **450***a* is secured to the first sternoclavicular brace **425**, such that the axis **421** (see **FIG. 4**) is coaxial with the first sternoclavicular axis **435**. The elastic element **411** is attached to the first sternoclavicular extension **431** through the hole **416**. The housing **401** of the MLB **450***b* is fixed to the sternoclavicular bracket **426** such that the axis **421** is coaxial with the second sternoclavicular axis **436**. The elastic element **411** is attached to the second sternoclavicular extension **433**.

[**0043**] Referring to **FIGS. 7, 8,** and **9**, the shoulder module **420** consists of three MLBs **450***c*, **450***d* and **450***e*, a first shoulder brace **441**, a shoulder bracket **442**, a second shoulder brace **443** with an upper arm harness **444**, a shoulder arch bracket **445**, a shoulder planet gear **446**, a first shoulder counter weight **447** installed on the shoulder bracket **442**, and a second shoulder counter weight **448** installed on the shoulder arch bracket **445**. The first shoulder brace **441** comprises a first shoulder slot **449** to secure the shoulder module **420** to the sternoclavicular module **410** by means of the shoulder coupling **470**. The shoulder bracket **442** has a first shoulder extension **451**. The second shoulder brace **443** has a shoulder slides **452** and a second shoulder slot **453** to secure the shoulder module **420** to the elbow module **430** by means of the elbow coupling **480**. The shoulder arch bracket **445** includes a shoulder internal-toothed gear **454**, a shoulder arch slot **455**, and a second shoulder extension **456**. The shoulder internal-toothed gear **454**, and the shoulder arch slot **455** have mutual a first shoulder axis **457**. The shoulder planet gear **446** has a third shoulder extension **458**. The first shoulder brace **441** and the shoulder arch bracket **445** are mounted on the shoulder bracket **442** and can be rotated around a second shoulder axis **459** and a third shoulder axis **461** respectively. The second shoulder axis intersects the third shoulder axis **461** at 90 angle in a shoulder point **462**. The shoulder slide **452** is installed in the shoulder arch slot **455** and can be moved along the shoulder arch slot **455**. The shoulder planet gear **446** is installed in the shoulder slides **452**, can be rotated into the shoulder slides **452** around a shoulder auxiliary axis **463**, can be moved along the shoulder arch slot **455** together with the shoulder slide **452**, and permanently engaged with the shoulder internal-toothed gear **454**. The first shoulder axis **457** intersects the second shoulder axis **459** and the third shoulder axis **461** at 90 degree angle in the shoulder point **462**. The housing **401** of the MLB **450***c* is secured to the first shoulder brace **441** such that the axis **421** is coaxial with the first shoulder axis **459**. The elastic element **411** is attached to the first shoulder extension **451** through the hole **416**. The housing **401** of the MLB **450***d* is secured to the shoulder bracket **442** such that the axis **421** is coaxial with the third shoulder axis **461**. The elastic element **411** is attached to the second shoulder extension **456** through the hole **416**. The housing **401** of the MLB **450***e* is secured to the second shoulder brace **443** such that the axis **421** is coaxial with the shoulder auxiliary axis **463**. The elastic element **411** is attached to the third shoulder extension **458** through the hole **416**.

[**0044**] Referring to **FIGS. 10, 11,** and **12**, the elbow module **430** consists of two MLBs **450***f* and **450***g*, a first elbow brace **465,** an elbow arch bracket **466**, a second elbow brace **467**, an elbow planet gear **468**, and an elbow counter weight **469** installed on the elbow arch bracket **466**. The first elbow brace **465** has a first elbow slot **471** to secure the elbow module **430** to the elbow coupling **480**. The elbow arch bracket **466** comprises an elbow internal-toothed gear **472**, an elbow arch slot **473**, and a first elbow extension **474**. The elbow internal-toothed gear **472** and the elbow arch slot **473** have mutual a first elbow axis **475**. The second elbow brace **467** has an elbow slides **476**, a forearm harness **477**, and a second elbow slot **478** to secure the elbow module **430** to the wrist coupling **490**. The elbow planet gear **468** includes a second elbow extension **479**. The first elbow brace **465** is mounted on the elbow arch bracket **466** and can be rotated around a second elbow axis **481**. The second elbow axis **481** intersects the first elbow axis **475** at 90-degree angle in an elbow point **482**. The elbow slide **476** is installed in the elbow arch slot **473** and can be moved along the elbow arch slot **473**. The elbow planet gear **468** is installed in the elbow slides **476**, can be rotated into the elbow slides **476** around an elbow auxiliary axis **483**, can be moved along the elbow arch slot **473** together with the elbow slide **476**, and permanently engaged with the elbow internal-toothed gear **472**. The housing **401** of the MLB **450***f* is secured to the first elbow brace **465** such that the axis **421** is coaxial with the second elbow axis **481**. The elastic element **411** is attached to the first elbow extension **474** through the hole **416**. The housing **401** of the MLB **450***g* is secured to the second elbow brace **467** such that the axis **421** is coaxial with the elbow auxiliary axis **483**. The elastic element **411** is attached to the second elbow extension **479** through the hole **416**.

[**0045**] Referring to **FIG. 13**, the wrist module **440** consists of two MLBs **450***h* and **450***i*, a first wrist brace **485**, a wrist bracket **486**, a second wrist brace **487** with a hand harness **488**, and a wrist counter weight **489** installed on the wrist bracket **486** to balance the force of gravitation. The first wrist brace **485** has a wrist slot **491** to secure the wrist module **440** to the elbow module **430** by means of the wrist coupling **490**. The first wrist brace **485** has a first wrist extension **492**. The wrist bracket **486** has a second wrist extension **493**. The first wrist brace **485** and the second wrist brace **487** are mounted on the wrist bracket **486** and can be rotated around a first wrist axis **494** and a second wrist axis **495** respectively. The first wrist axis **494** intersects a second wrist axis **495** at the 90-degree angle in the wrist point **496**. The housing **401** of the MLB **450***h* is secured to the wrist bracket **486** such that the axis **421** is coaxial with the first wrist axis **494**. The elastic element **411** is attached to the first wrist extension **492** through the hole **416**. The housing **401** of the MLB **450***i* is fixed to the second wrist brace **487** such that the axis **421** is coaxial with the second wrist axis **495**. The elastic element **411** is attached to the second wrist extension **493** through the hole **416**.

[**0046**] Referring to **FIG. 14**, the sternoclavicular coupling **460** consists of a sternoclavicular coupling brace **505**, a first sternoclavicular coupling adapter **510**, a second sternoclavicular coupling adapter **515** and a sternoclavicular coupling mount **520**. The sternoclavicular coupling brace **505** comprises a sternoclavicular spherical hole **506** and a sternoclavicular coupling slot **507**. The first sternoclavicular coupling adapter **510** includes a first sternoclavicular slide **511** and a second sternoclavicular slide **512**. The second sternoclavicular coupling adapter **515** has an outer sternoclavicular sphere **516** and a third sternoclavicular slide **517**. The sternoclavicular coupling mount **520** has a rotation preventing orifice **521**, for example, of a polygonal shape, and a mount coupling slot **522**. The first sternoclavicular coupling adapter **510** is secured to the sternoclavicular coupling brace **505** by means of the second sternoclavicular slide **512** that can be moved along the sternoclavicular coupling slot **507**. The second sternoclavicular coupling adapter **515** is secured to the sternoclavicular coupling brace **505** by means of the outer sternoclavicular sphere **516** that can be rotated in the sternoclavicular spherical hole **506**. The second sternoclavicular coupling adapter **515** is secured to the first slot **431** of the sternoclavicular module **410** by means of the third sternoclavicular slide **517** which can be moved along the slot **431**. The first sternoclavicular coupling adapter **510** is secured to the sternoclavicular coupling mount **520** by means of the first sternoclavicular slide **511,** which can be moved along the mount coupling slot **522**. The sternoclavicular coupling mount **520** is secured to a stationary object, for example, to a polygonal wall-mounted beam **200** by means of the polygonal orifice **521**.

[**0047**] Referring to **FIG. 15**, the shoulder coupling **470** consists of a shoulder coupling brace **525**, a first shoulder coupling adapter **530,** and a second shoulder coupling adapter **535**. The shoulder coupling brace **525** comprises a shoulder spherical hole **526** and a shoulder coupling slot **527**. The first shoulder coupling adapter **530** includes a first shoulder coupling slide **531** and a second shoulder coupling slide **532**. The second shoulder coupling adapter **535** has an outer shoulder sphere **536** and third shoulder coupling slide **537**. The first shoulder coupling adapter **530** is secured to the shoulder coupling brace **525** by means the second shoulder coupling slide **532** which can be moved along the shoulder coupling slot **527**. The second shoulder coupling adapter **535** is secured to the shoulder coupling brace **525** by means of the outer shoulder sphere **536** which can be rotated in the shoulder spherical hole **526**. The second shoulder coupling adapter **535** is secured to the second sternoclavicular slot **434** of the sternoclavicular module **410** by means of the third shoulder coupling slide **537** which can be moved along the slot **434**. The shoulder module **2** is secured to the first shoulder coupling adapter **530** by means of the first shoulder coupling slide **531** which can be moved along the first slot **449** of the shoulder module **420**.

[**0048**] Referring also to **FIG. 16**, the elbow coupling **480** consists of an elbow coupling brace **540**, a first elbow coupling adapter **545**, and a second elbow coupling adapter **550**. The elbow coupling brace **540** comprises an elbow spherical hole **541** and a brace elbow coupling slot **542**. The first elbow coupling adapter **545** includes a first elbow coupling slide **546** and a second elbow coupling slide **547**.

The second elbow coupling adapter **550** has an outer elbow sphere **551** and a third elbow coupling slide **552**. The first elbow coupling adapter **545** is secured to the elbow coupling brace **540** by means of the second elbow coupling slide **547** which can be moved along the brace elbow coupling slot **542**. The second elbow coupling adapter **550** is secured to the elbow coupling brace **540** by mean of the outer elbow sphere **551** which can be rotated into the elbow spherical hole **541**. The first elbow coupling adapter **545** is secured to the second shoulder slot **453** of the shoulder module **420** by mean of the first elbow coupling slide **546** which can be moved along the slot **453**. The elbow module **430** is secured to the second elbow coupling adapter **550** by means of the third elbow coupling slide **552** which can be moved along the first elbow slot **471** of the elbow module **430**.

[**0049**] Referring also to **FIG. 17**, the wrist coupling **490** consists of a wrist coupling brace **555**, a first wrist coupling adapter **560**, and a second wrist coupling adapter **565**. The wrist coupling brace **555** comprises a wrist spherical hole **556** and a brace wrist coupling slot **557**. The first wrist coupling adapter **560** includes a first wrist coupling slide **561** and a second wrist coupling slide **562**. The second wrist coupling adapter **565** has an outer wrist sphere **566** and a third wrist coupling slide **567**. The first wrist coupling adapter **560** is secured to the wrist coupling brace **555** by means of the second wrist coupling slide **562** which can be moved along the brace wrist coupling slot **557**. The second wrist coupling adapter **565** is secured to the wrist coupling brace **555** by means of the outer wrist sphere **566** which can be rotated into the wrist spherical hole **556**. The first wrist coupling adapter **560** is secured to the second elbow slot **478** of the elbow module **430** by means of the first wrist coupling slide **561** which can be moved along the slot **478**. The wrist module **440** is secured to the second wrist coupling adapter **565** by means of the third wrist coupling slide **567** which can be moved along the wrist slot **491** of the wrist module **440**.

[**0050**] In operation, before testing/exercising, the ES **400** is disposed on the user **100** in such a way, that the first sternoclavicular axis **435** and the second sternoclavicular axis **436** of the sternoclavicular module **410** are placed to coincide with anatomical rotation axes **103** and **104** of the sternoclavicular joint **101** respectively (see **FIGS. 1 and 6**). Therefore, the sternoclavicular point **437** coincides with the anatomical center of rotation in the sternoclavicular joint **101**. To provide this setting of the ES **400** the mount **520** (see **FIG. 14**) is secured to a stationary object, for example, to a wall mounted polygonal beam **200**. The first adapter **510** together with the brace **505**, the second adapter **515**, and the sternoclavicular module **410** are moved relative to the mount **520** in the slot **522** of the mount **520**. The brace **505** together with the second adapter **515** and the sternoclavicular module **410** are moved relative to the first adapter **510** in the second slide **512** of the first adapter **510**. The second adapter **515** together with the sternoclavicular module **410** is rotated relative to the brace **505** in the spherical hole **506** of the brace **505**. The sternoclavicular module **410** is moved relative to the second adapter **515** in the third slide **517** of the second adapter **515**. Those transpositions can be either apart or simultaneously. After that the required position of the sternoclavicular module **410** is affixed (fixing elements of the sternoclavicular coupling **460**, the shoulder coupling **470**, the elbow coupling **480**, and the wrist coupling **490** are not shown for clarity). Then, the shouldergirdle harness **428** is secured to a shouldergirdle **102** by a belt (not shown).

[**0051**] The shoulder module **420** is installed in such a way that first, second, and third shoulder axes **457**, **459**, and **461** of the shoulder module **420** are placed to coincide with the anatomical rotation axes **107**, **109**, and **108** of the shoulder joint **106** respectively (see **FIGS. 1 and 7**). Therefore, the shoulder point **462** coincides with the anatomical center of rotation in the shoulder joint **106**. In order to accomplish those coincidences, like so as for the sternoclavicular module **410**, the brace **525** (see **FIG. 15**) together with the shoulder module **420** are rotated and moved relative to the sternoclavicular module **410** by means of the adapter **536**, and the shoulder module **420** is moved relative to the brace **525** by means of the adapter **530**. Thus, the required position of the shoulder module **420** of the ES **400** on the user's upper extremity is achieved and affixed. Then, the shoulder harness **444** is secured to the upper arm **105** by a belt (not shown).

[**0052**] The elbow module **3** is installed in such a way that first and second elbow axes **475** and **481** of the elbow module **430** are placed to coincide with the anatomical rotation axes **112** and **114** of the elbow joint **111** respectively (see **FIGS. 1 and 10**). Therefore, the elbow point **482** coincides with the anatomical center of rotation of the elbow joint **111**. To accomplish this situation, like so as for the sternoclavicular module **410**, the brace **540** (see **FIG. 16**) together with elbow module **430** are moved relative to the shoulder module **420** by means of the adapter **545**, and the elbow module **430** is rotated and moved relative to the brace **540** by means of the adapter **550**. When the required position of the elbow module **430** is achieved, that position is affixed, and the elbow harness **477** is secured to a forearm **110** by a belt (not shown).

[**0053**] The wrist module **440** is installed in such a way that first and second elbow axes **494** and **495** of the wrist module **440** are placed to coincide with the anatomical rotation axes **117** and **118** of the wrist joint **116** respectively (see **FIGS. 1 and 13**). Therefore, the wrist point **496** coincides with the anatomical center of rotation in the wrist joint **116**. For this, like so as for the sternoclavicular module **410**, the brace **555** (see **FIG. 17**) together with the wrist module **410** are rotated and moved relative to the elbow module **430** by means of the adapter **565**, and the wrist module **440** is moved relative to the brace **555** by means of the adapter **560**. Thus, the required position of the wrist module **440** of the ES **400** is achieved and affixed. Then, the hand harness **488** is secured to the user's hand **115** by a belt (not shown).

[**0054**] Muscular contractions have two basic regimes: isometric in which the length of the muscle remains constant while the muscle works against resistance and isotonic in which the muscle remains under relatively constant tension while its length changes. Thus, in an isometric mode exercise, positions of the user's segment are not changed, and muscles cannot overcome exercising resistance. In an isotonic mode exercise, positions of the user's segments are changed because exercising resistance is less then muscle forces.

[**0055**] For testing/exercising in the isometric mode, the predetermined space position of module rotation points **437**, **462**, **482**, and **496** and its axes, which determine joint angles of the user's arm, have to be installed and fixed. For providing an easy those operations, in each MLB **450***a*-**450***i* (see **FIGS. 3, 4, and 5**) the cross section area of the channel **404** should be wide opened by the valve **408**. The support

412 together with the elastic element **411** and the disk **418** are rotated about the axis **421**, and the indicator **417** reads the required joint angle. Because the elastic element **411** is connected with corresponding extension in every module, those extensions are turned together with the corresponding parts of the modules **410-440**. To affix installed angle, the cross-section area of the channel **404** is filly blocked by the valve **408**, and the piston **405** is not able to move.

[**0056**] In a case of a multi-joint complex locomotor act, the user attempts to execute a predetermined arm motion, for example, to take a piece of paper from a table. As mentioned above, the elastic element **411** has a very small elastic deformation. Because of this, live motions of the shouldergirdle **102**, the upperarm **105**, the forearm **110** and the hand **115** will not occur. But almost all muscles of the user's arm participate in isometric muscular contractions, and all MLBs **450***a*-**450***i* are affected.

[**0057**] In a case of a mono-joint locomotor act, for instance, the upperarm abduction-adduction, the user attempts to rotate the upperarm **105** about the axis **108** outward and inward relative to his torso. Remainder segments of the arm and muscles are enervated. For the upperarm abduction-adduction the MLB **450***c* only is affected.

[**0058**] In the isotonic mode of operation, for each MLB **450***a*-**450***i* a predetermined testing/exercising load is fixed by adjusting the valve **408**. In this mode of operation the testing/exercising load in the MLBs **450***a*-**450***i* can be either the same or vary according to the testing/exercising program.

[**0059**] In the case of a multi-joint complex locomotor act, the user executes a predetermined arm movement, for example, to take and move a piece of paper on a table. Almost all muscles and segments of the arm participate in that live motion. All MLBs **450***a*-**450***i* are affected in the same way as for the case of the isometric multi-joint complex locomotor act. The channel **404** is not blocked in this mode and the gear shaft **407** with the support **412** and the elastic element **411** can be rotated. When the corresponding extension exerts the elastic element **411**, the last is deformed. When the user overcomes the testing/exercising load, the elastic element **411** starts to turn together with the disk **418**.

[**0060**] On FIGS. **18-20**, the second embodiment of the present invention is shown. In this embodiment each of the rotation axis of the modules **410**, **420**, and **430** is interconnected with corresponding rotation axis of the MLB **450** by means of a cable system **600**. The resistance device (see **FIGS. 19 and 20**) comprises a driving gear **571** and a pulley **572**. The gear **571** and the pulley **572** are immovable relative to each other but can be rotated in a base **573**. The pulley **572** can receive a cable **574**. The driving gear **571** is permanently engaged with a driven gear **576**. The driven gear **576** is jointed to the first end of a connection rod **577** through a pin **578**. The second end of the connecting rod **577** is jointed to the piston **579** through a pin **589**. The piston **579** can be moved in a cylinder **581** between its front and rear ends. The cylinder **581** is secured to the base **573**. The cylinder **581** having a channel **582** is filled in operation with incompressible fluid. The channel **582** connects the front and the rear ends of the cylinder **581**, and can not be blocked by the piston **579**. The cross-section area of the channel **582** can be adjusted by a valve **583** that is manually operated by a handle **584**. To take a muscle force and/or exercise load reading, a pressure gage **586** is installed in the cylinder **581**. The goniometric device involves an arrow **587** secured to the base **573** and a scale **588** affixed to the pulley **572** to take a joint angle alteration reading,

[**0061**] Thus, the exoskeleton structure, according to the present invention, is able to provide testing and exercising of whole upper extremity of a user in a realistic manner. The exoskeleton structure can provide a biomechanical information about a user's upper extremity either simultaneously for all the joints or selectively for a joint of interest. The exoskeleton structure also can read the information either about a single anatomical motion of the user's upper extremity or a combination of anatomical motions of any complexity. Based on the information, the apparatus can provide a dosed load to user's given motions, and by this a proper exercise and rehabilitation program can be achieved.

[**0062**] While the exoskeleton structure for upper extremity testing and exercising according to the invention have been described in details above, it is clear that there are variations and modifications to this disclosure here and above which will be readily apparent to one of the ordinary skills in the art. To the extent that such variations and modifications of the present disclosure of the exoskeleton structure, wherein all axes of joint rotation in the exoskeleton structure are coincided with corresponding anatomical joints of a user's upper extremity, and all portions in the exoskeleton structure are interconnected so as described in the present disclosure, such are deemed within the scope of the present invention.

We claim:

1. An upper extremity exoskeleton structure for test and exercise comprising:

a plurality of links, a plurality of revolute joints, and a plurality of measuring-loading blocks wherein each said measuring-loading block having a resistance mechanism, a force sensor, and an angle sensor connected with said links through said revolute joints, and said links jointed to each other by said revolute joints forming a sternoclavicular, a shoulder, an elbow and a wrist modules;

said sternoclavicular module includes a shouldergirdle harness, two said measuring-loading blocks, two said revolute joints and said links wherein rotation axes of said revolute joints intersect each other at 90-degree angle;

said shoulder module includes an upper arm harness, three said measuring-loading blocks, three said revolute joints and said links wherein said rotation axes of said revolute joints intersect each other at 90-degree angle;

said elbow module includes a forearm harness, two said measuring-loading blocks, two said revolute joints and said links wherein said rotation axes of said revolute joints intersect each other at 90-degree angle;

said wrist module includes a hand harness, two said measuring-loading blocks, two said revolute joints and said links wherein said rotation axes of said revolute joints intersect each other at 90-degree angle;

a plurality of means to connect said modules with each other forming said exoskeleton structure;

a plurality of means to compensate anthropometrical differences of the upper extremities between different users;

a means to secure said exoskeleton structure to a stationary object;

a plurality of means to counterbalance said exoskeleton structure.

2. An exoskeleton structure to claim 1,

wherein said rotation axes of said exoskeleton structure, being secured to a user's upper extremity, intersect each other in the center of the user's sternoclavicular joint for said sternoclavicular module, in the center of the user's shoulder joint for said shoulder module, in the center of the user's elbow joint for said elbow module, and in the center of the user's wrist joint for said wrist module.

3. An exoskeleton structure to claim 1,

wherein number of said modules connected by said plurality of connecting means forming said exoskeleton structure is changeable in accordance with the predetermined locomotor act and user's joints participating in that locomotor act.

4. A method for an upper extremity test and exercise comprising:

a disposition of said exoskeleton structure on said user's upper extremity in such a way where each said rotation axis of said modules coincides with corresponding anatomical axis of anatomical joints of the user's upper extremity for each anatomical rotation of segments of the user's upper extremity in anatomical joints;

a securement of said exoskeleton structure to upper extremity segments in such a way where said disposition of said rotation axes of said modules is preserved during whole cycle of the predetermined locomotor act;

an adjustment selectively of an exercise load in each said resistance mechanism of said exoskeleton structure in accordance with the predetermined locomotor act;

a performing of the predetermined locomotor act by the user;

a measurement of muscle forces and joint angles of the user's upper extremity by said force sensors, and said angle sensors of said exoskeleton structure.

5. A method to claim 4,

wherein the anatomical joints of the user's upper extremity that being loaded and measured by said exoskeleton structure are a sternoclavicular joint with its two anatomical rotations, a shoulder joint with its three anatomical rotations, an elbow joint with its two anatomical rotations, and a wrist joint with its two anatomical rotations.

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