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(54) **Automatic anti-roll stabilization system of a watercraft**

Automatisches Antirollstabilisierungssystem eines Wasserfahrzeugs

Système antiroulis automatique pour la stabilisation d'un bateau

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Description

[0001] The present invention relates to an automatic anti-roll system for the stabilization of the rolling of a watercraft, comprising a stabilizing fin that can turn about an axis, sensor means for detecting the motions of roll of the watercraft, and a control device for governing rotation of said fin about said axis as a function of signals supplied by said sensor means.

[0002] Stabilizing fins are basically hydrodynamic profiles (similar to airfoil profiles), which are mounted in a transverse direction with respect to the hull in order to reduce the transverse motions of roll (rotations about the longitudinal axis of the hull) induced by the action of the waves. The hydrodynamic profile impinged upon by the flow of water in relative motion with respect to the hull generates a force of hydrodynamic lift that varies, among other things, as a function of the angle of incidence of the profile. The stabilizing fin is associated to a control device that varies the angle of incidence of the hydrodynamic profile as a function of signals indicating rolling of the watercraft.

[0003] In traditional solutions, the stabilizing fin is associated to a mechanical actuator having a rotating shaft, the bottom end of which comes out of the hull and is connected to the stabilizing fin. The top part of the shaft of the mechanical actuator is fixed to a rocker, to which two hydraulic cylinders are mechanically connected. The linear motion of the hydraulic cylinders is converted into a motion of rotation of the shaft of the mechanical actuator via the rocker, which also has the function of torque amplifier.

[0004] A typical system of anti-roll stabilization of a known type is characterized by the following operating parameters:

- angular motion of the stabilizing fin with respect to its central position: +/- 30°;
- driving speed: between 22°/s up to a maximum of 60°/s;
- driving at high torque and low power;
- maximum speed of rotation: 6-8g/1'.

[0005] The motion of the hydraulic cylinders is ensured by an on-board hydraulic system governed by a proportional directional valve. The proportional valve receives a voltage signal of +/-10 V processed by an electronic control system.

[0006] In the known solutions, the electronic control system comprises a control panel containing a regulator of a PLC type. The electronic control system is associated to a system of sensors for detecting motions of roll, comprising an inclinometer that measures the angle of roll and a gyroscope that measures the speed of roll.

[0007] The electronic regulator processes the signal supplied by the sensors and generates a voltage signal that determines opening of the proportional valve. The flow of oil that traverses the proportional valve governs linear advance of the cylinders and hence rotation of the rocker. There follows a rotation of the axis of the mechanical actuator and hence of the stabilizing fin. Corresponding to the presumed new angle of incidence is a new value of the force of hydrodynamic lift and hence of the rectifying moment generated on the watercraft. Said rectifying moment tends to offset the destabilizing moment generated by the impact of the waves on the watercraft.

[0008] The performance of the entire stabilizing system is markedly affected by the dynamic response of the following three subassemblies:

- mechanical actuator and stabilizing fin;
- hydraulic control system;
- electronic regulating system.

[0009] The dynamic response of the electronic regulating system is certainly better than the performance required. Also the mechanical actuator in practice can yield good results in terms of dynamic response. The critical aspect of the system is represented by the dynamic behaviour of the hydraulic system.

[0010] The design and construction of the hydraulic control system is subject to numerous constraints, amongst which:

- need to use standard oleodynamic elements available on the market;
- head losses generated by the system of tubes and within the proportional regulating valve;
- noise of the system, which limits the working pressure to values of not higher than 120-135 bar;
- low efficiency of the oleodynamic system (the efficiency between the installed power of the motor and the shaft of the mechanical actuator is lower than 50%);
- need to provide a cooling system for dissipating the heat generated by the losses of efficiency; and
- weight and complexity of the oleodynamic system, and difficulty of installation and of management.

[0011] The aforesaid constraints affect and penalize the dynamic response of the hydraulic control system and consequently the entire stabilizing system.

[0012] The majority of stabilizing systems used today envisage the option of stabilization at anchor, i.e., with the watercraft stationary. In these conditions, since the speed of the flow that impinges upon the hydrodynamic profile is practically zero, the amplifying effect of the force of hydrodynamic lift ceases, and the mode of control is purely of an impulsive nature. Frequently, the motions of stabilization at anchor are at a high frequency, so that it is necessary to have available a actuation system with a high dynamic range. This calls for an available power higher than the one used in navigation.

[0013] To achieve a good stabilization at anchor it is indispensable to be able to turn the stabilizing fin at a high speed, in the region of 45-60°/s. To obtain these performance levels, the hydraulic control system must work at a high power and, in these conditions, there are high levels of dissipation. The efficiency of the hydraulic transmission in these operating conditions is estimated in the region of 30-35%. In such conditions, also the dynamic loads to which the mechanical actuator is subjected become high, and this entails an oversizing of the mechanics and hence an increase in the inertias of the mechanical actuator system. This markedly penalizes the dynamic response of the entire system, rendering at times impossible the use of such a system for the function of stabilization at anchor.

[0014] US-A-4926778 discloses a high speed planing watercraft including a pitch stabilization system having variable pitch airfoils controlled by a control system.

[0015] US-A-3371642 discloses a trim control device for boats including a pair of rearwardly extending plates on the stern of the boat, which form extensions on the bottom surface area thereof.

[0016] US-A-3020869 discloses an anti-roll stabilizing system for marine vessels including an anti-roll stabilizing fin driven by an hydraulic motor connected to an hydraulic pump by means of hydraulic lines.

[0017] GB 999 306 discloses an anti-roll stabilizing system for marine vessels including an anti-roll stabilizing fin driven by an electric motor.

[0018] More specifically, the present invention relates to an automatic anti-roll system for the stabilization of the rolling of a watercraft according to the preamble of Claim 1, which is known, e.g. from EP 1 577 210 A1.

[0019] The object of the present invention is to provide an automatic anti-roll system for the stabilization of the rolling of a watercraft that will enable the aforesaid problems to be overcome.

[0020] According to the present invention, this object is achieved by an automatic anti-roll system according to claim 1.

[0021] The electronic regulating system of the system according to the present invention is simpler and at the same time more flexible and powerful than the electronic systems used for control of oleodynamic systems.

[0022] The electronic control system associated to an electric motor enables creation of new, very sophisticated, and highly adaptive algorithms of regulation. This aspect is of fundamental importance for providing a stabilizing system at anchor without penalizing the system as a whole, as occurs in traditional solutions.

[0023] Further characteristics and advantages of the present invention will emerge clearly in the course of the ensuing detailed description, which is provided purely by way of non-limiting example with reference to the attached drawings, wherein:

- Figure 1 is a schematic perspective view of a system for anti-roll stabilization of watercraft according to the present invention;
- Figure 2 is a schematic cross-sectional view according to the line II-II of Figure 1; and
- Figure 3 is an exploded perspective view of the actuator assembly designated by the arrow III in Figure 1.

[0024] With reference to Figure 1, designated as a whole by 10 is an automatic system for anti-roll stabilization of watercraft. The stabilizing system 10 comprises a stabilizing fin 12, an actuator assembly 14 and an electronic regulating system 16.

[0025] The stabilizing fin 12 is able to turn about an axis 18 and is shaped according to a hydrodynamic profile. The actuator assembly 14 is designed to govern rotation of the stabilizing fin 12 about the axis 18.

[0026] As illustrated in greater detail in Figures 2 and 3, the actuator assembly 14 comprises a fixed support 20, rotatably supported within which is a shaft 22, to which the stabilizing fin 12 is fixed. Preferably, two taper bearings 24 are provided for support of the shaft 22.

[0027] The actuator assembly 14 according to the present invention comprises an electric motor 26 and a motor reducer28. The electric motor 26 is preferably constituted by a permanent-magnet d.c. electric motor (brushless motor). The motor reducer28 is preferably an epicyclic motor reducer with input and output at 90° apart. The input shaft of the motor reducer 28 is fitted on the output shaft of the electric motor 26. The output shaft of the motor reducer 28 is fixed with respect to the shaft 22 that bears the stabilizing fin 12.

[0028] The electronic regulating system 16 comprises sensor means 30 for detecting the motions of rolling of the watercraft, a microprocessor regulating unit 32, and a driving unit 34.

[0029] The sensor means 30 preferably comprise at least one sensor for detecting the angle of roll and at least one sensor for detecting the speed of roll. The sensor of the angle of roll can be an inclinometer, and the sensor of the speed of roll can be a gyroscope. The microprocessor regulating unit 32 receives the data on the motions of roll of the watercraft and processes the reference signals to be sent to the driving unit 34. Preferably, the driving unit 34 carries out a control of the angular position of the stabilizing fin 12 by means of an absolute encoder 36 mounted on the shaft of the electric motor 26.

[0030] The electronic regulating system 16 according to the present invention enables adjustment of the stabilizing fin 12 in a way that is far more sophisticated than is possible with electro-hydraulic systems according to the known art. Traditional PLC regulators supply only a voltage signal corresponding to an angle of rotation of the fin, from which there is presumed a force of hydrodynamic lift generated by the profile and hence a torque that counters the torque of roll.

[0031] With the regulating system 16 according to the present invention it is possible to carry out control of different reference values of the electric motor 26, amongst which: power, torque, speed, position, power absorption/load.

[0032] The reading and control of the aforesaid parameters enables creation of very sophisticated and highly adaptive algorithms of regulation.

[0033] Thanks to the fact that the actuator assembly 14 has a high dynamics and supplies satisfactory responses over a wide range of operating frequencies, the electronic regulating system 16 can create algorithms and laws of control not only as a function of the disturbance generated by the waves but, above all, as a function of the actual responses of the watercraft. This aspect is fundamental for the construction of a good stabilizing system at anchor, without penalizing the system as a whole, as occurs in the known art.

[0034] In the traditional solutions with oleodynamic control, the adjustment of the stabilizing fin 12 is based upon hydrodynamic laws, assuming that the actual operation approaches the calculated one. This approach, however, neglects a series of phenomena, amongst which the interference between the hull and the stabilizing fin, that are difficult to evaluate with numerical simulations or tank tests.

[0035] With the system according to the present invention it is possible to monitor the operating parameters of the actuator assembly 14 easily (power, torque, speed, position, power absorption/load). This enables evaluation of the real dynamic behaviour of the stabilizing fin 12 and identification of its dynamics. The real operating data enable identification of the hydrodynamic profiles used and enable the due modifications to be made.

[0036] As compared to the known art, the advantages that derive from the use of the stabilizing system according to the present invention are the following:

- the actuator assembly 14 has a better dynamics as compared to actuators of a mechanical type;
- the coefficient of efficiency of the control device is higher, and a reduction of the installed power is consequently obtained;
- a reduction of the dynamic loads on the actuator 14 is obtained: in fact, the loads act exclusively in the axial direction, and there are no mechanical linkages subjected to high dynamic loads;
- a reduction of the structural loads on the hull is obtained;
- a drastic reduction of the noise is obtained, and hence a higher comfort on board;
- a better dynamics of the system is achieved, so that it is possible to obtain a regulator with higher performance both in navigation and in stabilization at anchor;
- installation on board is simplified as compared to the known solutions since no intervention of skilled labour is required;
- a better reliability of the system is achieved thanks to the smaller number of components installed (in the oleodynamic system according to the known art

leakage in a hydraulic connector is sufficient to jeopardize operation of the stabilizing system).

[0037] Tests conducted by the present applicant show that the actuator assembly 14 with electric motor and motor reducer affords a higher performance than an oleodynamic actuator according to the known art. The lower power losses of the electric motor moreover enable variation of the controller gains so as to improve further the efficiency of the system. This enables an adaptive controller to be obtained that is able to pass from one configuration of gains to a different one as required.

[0038] Of course, without prejudice to the principle of the invention, the details of construction and the embodiments may vary widely with respect to what is described and illustrated herein, without thereby departing from the scope of the invention as defined in the ensuing claims.

Claims

1. An automatic anti-roll system for the stabilization of the rolling of a watercraft at anchor, comprising:

   - a stabilizing fin (12) that can turn about an axis (18), the stabilizing fin (12) being configured for being mounted in a transverse direction with respect to the hull of the watercraft and having a hydrodynamic profile which, in use, is impinged upon by the flow of water in relative motion with respect to the hull to generate a force of hydrodynamic lift;
   - an actuator assembly (14), designed to govern rotation of said stabilizing fin (12) about said axis (18); and
   - a regulating system (16), designed to govern said actuator assembly (14) as a function of signals indicating rolling of the watercraft, said regulation system (16) comprising sensor means (30), designed to supply a signal indicating rolling of the watercraft;

   characterized in that said actuator assembly (14) comprises an electric motor (26) connected to said stabilizing fin (12) via a reduction gear (28), and that said regulating system is arranged for carrying out control of the angular position of the stabilizing fin (12) by means of an encoder (36) associated to said electric motor (26) and comprises:

   - a microprocessor regulating unit (32), designed to process the data on rolling of the watercraft supplied by said sensor means (30); and
   - a driving unit (34) for governing said electric motor (16).

2. The system according to Claim 1, **characterized in that** the regulating system (16) is arranged for controlling one or more of the following operating parameters of the electric motor (26): power, torque, speed, position, electrical power input, load.

3. The system according to Claim 1, **characterized in that** said electric motor (26) is a permanent-magnet d.c. motor.

Patentansprüche

1. Automatisches Anti-Roll-System für die Stabilisierung des Rollens eines Wasserfahrzeugs vor Anker, aufweisend:

- eine Stabilisierungsflosse (12), welche sich um eine Achse (18) herum drehen kann, wobei die Stabilisierungsflosse (12) dafür ausgelegt ist in einer Richtung quer in Bezug auf den Rumpf des Wasserfahrzeugs befestigt zu werden und wobei die Stabilisierungsflosse (12) ein hydrodynamisches Profil besitzt, welches im Betrieb von der Wasserströmung mit einer Relativbewegung in Bezug auf den Rumpf beaufschlagt wird, um eine hydrodynamische Hubkraft zu erzeugen;
- eine Aktuatoranordnung (14), welche ausgebildet ist eine Rotation der Stabilisierungsflosse (12) um die Achse (18) zu regeln; und
- ein Regulierungssystem (16), welches ausgebildet ist die Aktuatoranordnung (14) zu regeln als eine Funktion von Signalen, welche das Rollen des Wasserfahrzeugs anzeigen, wobei das Regulierungssystem (16) Sensormittel (30) aufweist, welche ausgebildet sind ein Signal bereitzustellen, welches ein Rollen des Wasserfahrzeugs anzeigt, wobei das Regulierungssystem (16) angeordnet ist, um eine Regelung der Winkellage der Stabilisierungsflosse (12) auszuführen mit Hilfe eines Encoders (36) und aufweist:

  - eine Mikroprozessorregelungseinheit (32), welche ausgelegt ist die Daten über das Rollen des Wasserfahrzeugs zu verarbeiten, welche von den Sensormitteln (30) bereitgestellt werden; und
  - eine Ansteuereinheit (34) zum Regeln des Elektromotors (16);

dadurch gekennzeichnet, dass

a) die Aktuatoranordnung (14) einen Elektromotor (26) aufweist, welcher über ein Planetenrad-Untersetzungsgetriebe (28) mit der Stabilisierungsflosse (12) verbunden ist; wobei eine Eingangswelle des Untersetzungsgetriebes (28) an einer Ausgangswelle des Elektromotors (26) angebaut ist und eine Ausgangswelle des Untersetzungsgetriebes (28) relativ zu einer Welle (22) befestigt ist, die die Stabilisierungsflosse (12) lagert, und das
b) der Encoder (36) mit dem Elektromotor (26) verbunden ist.

2. System gemäß Anspruch 1, **dadurch gekennzeichnet, dass** das Regulierungssystem (16) angeordnet ist, um eine oder mehrere der nachfolgenden Parameter des Elektromotors (26) zu regeln: Leistung, Drehmoment, Geschwindigkeit, Position, elektrische Eingangsleistung, Last.

3. System gemäß Anspruch 1, **dadurch gekennzeichnet, dass** der Elektromotor (26) ein Permanentmagnet-Gleichstrommotor ist.

Revendications

1. Système antiroulis automatique pour la stabilisation du roulis d'un engin nautique à l'ancre, comprenant :

- une ailette de stabilisation (12) qui peut tourner autour d'un axe (18), l'ailette de stabilisation (12) étant configurée pour être montée dans une direction transversale par rapport à la coque de l'engin nautique et ayant un profil hydrodynamique qui, en utilisation, est affecté par le flux d'eau en mouvement relatif par rapport à la coque pour générer une force de portance hydrodynamique ;
- un ensemble d'actionneur (14), conçu pour régir la rotation de ladite ailette de stabilisation (12) autour dudit axe (18) ; et
- un système de régulation (16), conçu pour régir ledit ensemble d'actionneur (14) en fonction de signaux indiquant le roulis de l'engin nautique, ledit système de régulation (16) comprenant un moyen de détection (30), conçu pour fournir un signal indiquant le roulis de l'engin nautique, où ledit système de régulation est agencé pour réaliser une commande de la position angulaire de l'ailette de stabilisation (12) au moyen d'un codeur (36) et comprend :

  - une unité de régulation de microprocesseur (32), conçue pour traiter les données sur le roulis de l'engin nautique fournies par ledit moyen de détection (30) ; et
  - une unité d'entraînement (34) pour régir ledit moteur électrique (16) ;

caractérisé en ce que :

a) ledit ensemble d'actionneur (14) comprend un moteur électrique (26) relié à ladite ailette de stabilisation (12) par l'intermédiaire d'un engrenage réducteur épicycloïdal (28), où un arbre d'entrée dudit engrenage réducteur (28) est monté sur un arbre de sortie dudit moteur électrique (26) et un arbre de sortie dudit engrenage

réducteur (28) est fixé par rapport à un arbre (22) qui porte ladite ailette de stabilisation (12), et **en ce que**
b) ledit codeur (36) est associé audit moteur électrique (26).

2. Système selon la revendication 1, **caractérisé en ce que** le système de régulation (16) est agencé pour commander un ou plusieurs des paramètres de fonctionnement suivants du moteur électrique (26) : la puissance, le couple, la vitesse, la position, la puissance électrique à l'entrée, la charge.

3. Système selon la revendication 1, **caractérisé en ce que** ledit moteur électrique (26) est un moteur à courant continu à aimant permanent.

FIG. 1

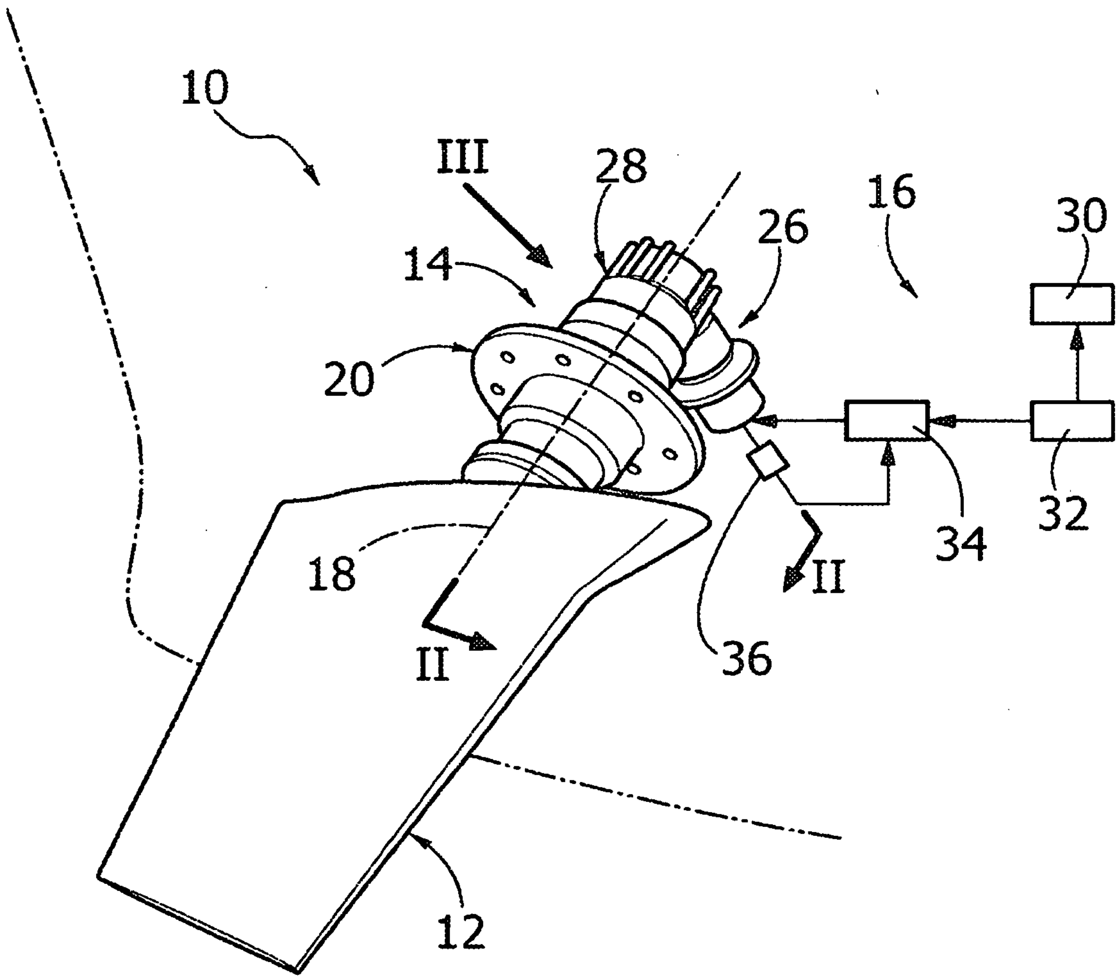


FIG. 2

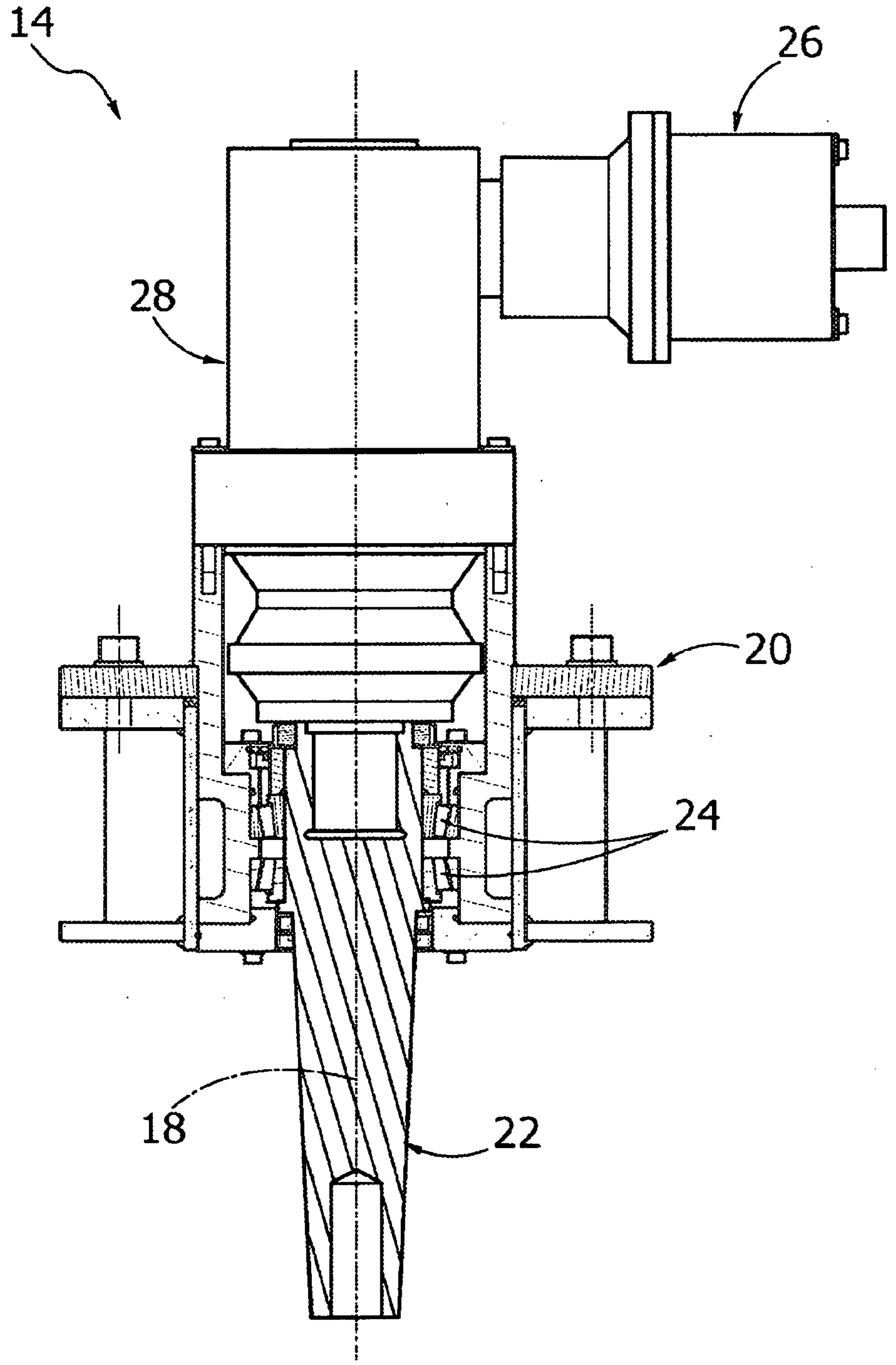
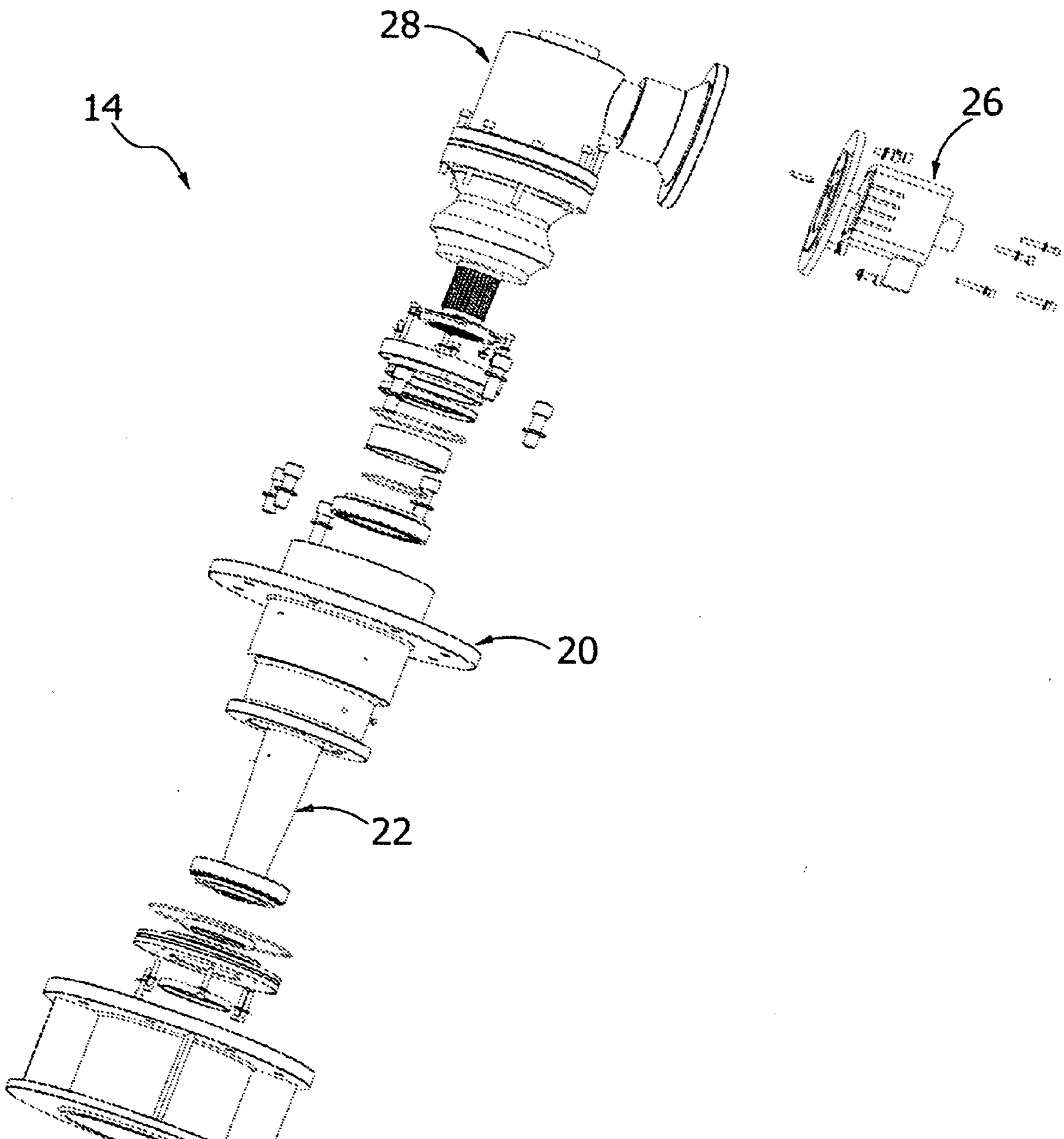


FIG. 3



REFERENCES CITED IN THE DESCRIPTION

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