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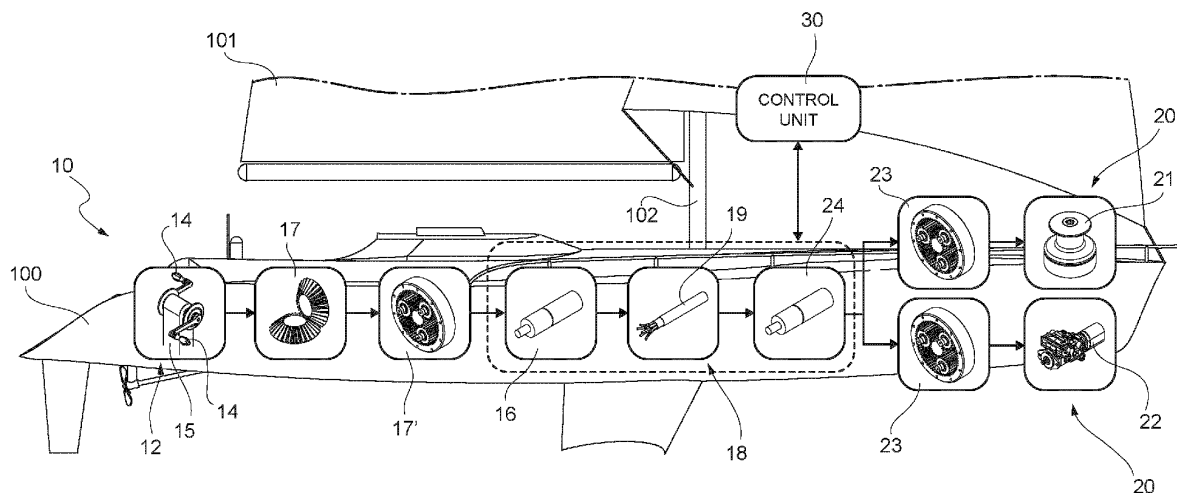
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**(54) ACTUATION SYSTEM FOR ACTUATORS IN A SAILBOAT**

(57) An actuation system (10) for actuating actuators in a sailboat (100) comprises, on board the sailboat (100): one or more driving elements (12), operable by crew operators; one or more actuators (20), configured to be driven by the driving elements (12), wherein the driving elements (12) are provided with a respective primary electric motor (16) and the actuators (20) are provided with a respective secondary electric motor (24). The system is further provided with an electrical circuit (18)

configured to electrically couple the primary (16) and secondary (24) electric motors, the primary electric motor (16) being configured to transform a driving motion of the respective driving element (12) into electric energy in the electrical circuit (18); and the secondary electric motor (24) being configured to transform electric energy in the electrical circuit (18) into an actuating motion of the respective actuator (20). The actuation system can also be associated with energy recovery functions.

**FIG. 2**

## Description

### CROSS-REFERENCE TO RELATED APPLICATIONS

**[0001]** This patent application claims priority from Italian patent application no. 102023000017706 filed on August 29, 2023, the entire disclosure of which is incorporated herein by reference.

### TECHNICAL FIELD

**[0002]** The invention relates to an actuation system for actuating actuators, in particular winches and/or hydraulic actuators, in sailboats, in particular in racing sailboats, or in general in competition sailboats. As will be described later, this system can also be associated with energy recovery functions.

### PRIOR ART

**[0003]** As is well known, winches are commonly used in sailboats to manoeuvre the sails (for example, to hoist, slack, lower, or adjust, i.e. trim, the sails). The function of the winches is to facilitate the adjustment of any line (sheets, halyards, lifts, etc.), that offers a certain resistance, acting as a mechanical power reducer and multiplying the force exerted by crew operators.

**[0004]** It is also known that hydraulic actuators (e.g., based on hydraulic actuation pumps and cylinders) are used, especially in larger boats, to operate various mechanisms such as, for example, masts, rudders, foils, or other types of appendages.

**[0005]** The actuation of the winches and the aforementioned hydraulic actuators by the crew is usually carried out using cranks or similar human-operated mechanisms, configured to be moved, usually with a rotational movement, by the crew operators and mechanically coupled, by means of suitable mechanical transmission systems, to respective winches or hydraulic actuators.

**[0006]** In particular, in the context of racing, or in general, competition sailboats, to which this discussion makes particular reference, these cranks are generally carried by pedestals which are installed on the deck of the boat and are operated by dedicated crew operators, the so-called "grinders". The role of the grinders is to exert mechanical power on the cranks (or similar actuation elements), which allows, in all sailing conditions, particularly during a race, the winches or the hydraulic actuators to be operated in a particularly fast time.

**[0007]** Figure 1 shows a possible winch actuation system, of a known type, generally denoted with 1.

**[0008]** This actuation system 1, in the example, comprises a pedestal 2, coupled to the deck 3 of a sailboat and carrying a pair of cranks 4, typically designed for the right hand and the left hand of a grinder.

**[0009]** The actuation system 1 comprises a mechanical transmission system, including transmission shafts and gears, which, in the example shown, couple the

motion of the cranks 4 to two winches 6, aligned with the pedestal 2 transversely to a longitudinal direction of extension of the deck 3, located at opposite sides with respect to the same pedestal 2. In a known manner, here not shown, the winches 6 are configured to implement the adjustment of respective lines (and, accordingly, of respective sails), depending on the actuation movement of the cranks 4 provided by the grinder.

**[0010]** In summary (and not shown in detail), the above-mentioned mechanical transmission system comprises, within the pedestal 2, a chain assembly, e.g. with a double speed ratio (to achieve a speed change that allows the winches to rotate faster or slower depending on the chosen speed requirement), coupled to the rotation shaft of the cranks 4, and also transmission shafts 8, connected to the chain assembly by means of respective gears and also coupled to respective winches 6 by means of respective transmission members 8' (shown schematically), for the transfer of the mechanical power generated by the movement of the same cranks 4.

**[0011]** Push buttons 9 (or similar elements) arranged at the base of the pedestal 2 allow the actuation of the cranks 4 to be mechanically connected to any of the winches 6 coupled to the same mechanical transmission system (while decoupling the other winches 6), so as to allow the grinder to operate the desired lines by pressing (e.g. with the foot) the associated push button.

**[0012]** In a manner not-shown, several pedestals 2 (with related cranks 4) may be installed on board the same sailboat and each of these pedestals 2 may be coupled by the described mechanical transmission system to a number of winches (and/or hydraulic actuators).

**[0013]** The actuation system described, while generally effective, has some drawbacks and issues.

**[0014]** Firstly, because it is a rather complex mechanical system (since each pedestal must be able to control each winch in order to allow maximum flexibility of use), it is sensitive to numerous design and production parameters that can have a significant impact on the overall efficiency of the system, which can typically be less than 50% (in multi-winch and multi-pedestal layouts).

**[0015]** In particular, since the transmission shafts are straight, there are severe restrictions on the arrangement of the components, which also require considerable overall dimensions for installation below deck.

**[0016]** Furthermore, in the case, which is possible, of operating a single winch from multiple pedestals by multiple grinders, for example by a first and a second grinder, it is required that the same grinders substantially exert the same drive torque; otherwise, in fact, the second grinder would actually be dragged by the first grinder (not actively contributing to the movement). As a result, such a usage scenario (with multiple grinders driving the same winch with different pedestals, for example to increase the power exerted and the speed of execution of the required manoeuvres) is not easy to implement in the actuation system described above.

**[0017]** There is therefore a need in the field, in parti-

cular in the context of racing, or in general, competition sailboats, to overcome or at least mitigate the above-mentioned drawbacks of known systems.

**[0018]** The aim of the present solution is to meet this need, preferably in a simple and reliable manner.

#### DESCRIPTION OF THE INVENTION

**[0019]** This aim is achieved by means of an actuation system as described in the appended claims.

#### BRIEF DESCRIPTION OF THE DRAWINGS

**[0020]** To better understand the invention, embodiments thereof are described hereinafter by way of non-limiting examples and with reference to the accompanying drawings, wherein:

- Figure 1 schematically shows a known actuation system for actuating actuators in a sailboat;
- Figure 2 is a schematic block diagram of an actuation system for actuating actuators in a sailboat, according to the present solution;
- Figures 3 and 5 show block diagrams of the actuation system of Figure 2, in different embodiments;
- Figure 4 schematically shows a possible configuration of the actuation system, according to one aspect of the present solution;
- Figure 6 is a summary diagram of a control logic in the actuation system;
- Figure 7 is a flow chart of operations performed by the control logic of the actuation system, according to a possible implementation; and
- Figures 8A-8C show diagrams of quantities relating to the control of the actuation system.

#### EMBODIMENTS OF THE INVENTION

**[0021]** As will be described in more detail below, a main aspect of the present solution is to create a virtual connection system, of the so-called "by-wire" type, i.e. without mechanical coupling, between at least one crank (or a similar human-operated drive element) and one or more winches (or similar actuators, e.g. hydraulic actuators) on board a sailboat.

**[0022]** The resulting actuation system (which may be referred to as "winch by-wire", for example, in the case of operating a winch, but which generally applies to any "actuator by-wire" on the boat) allows the restrictions of the known mechanical transmission systems to be overcome, by removing the mechanical transmission and replacing it with an electric actuation (i.e., provided using electrical cables and circuits).

**[0023]** As schematically shown in Figure 2, the by-wire actuation system, generally denoted with 10, comprises one or more human-operated driving elements 12, installed on board a sailboat 100 (shown schematically), so as to be operable by crew operators (e.g. by grinders, in

the case of racing or competition boats).

**[0024]** In a possible implementation, each human-operated driving element 12, as shown schematically, may comprise one or more cranks 14 (typically a pair) carried by a pedestal 15, having a base solidly coupled to the deck of the sailboat 100, in a suitable position to be reached by the crew.

**[0025]** In particular, according to one aspect of the present solution, each human-operated driving element 12 is coupled to a respective primary electric motor 16, which is configured to collect the motion of the same human-operated driving element 12 and transform it into electrical energy.

**[0026]** In the implementation illustrated, the primary electric motor 16 is coupled to the cranks 14 of the driving element 12, for example having its own rotation axis coupled to the rotation axis of the cranks 12 by a 90° joint 17 and a suitable gear system 17' (for example, of the planetary gear type).

**[0027]** The by-wire actuation system 10 comprises an electrical circuit 18, in particular including electrical cables 19, preferably of a flexible type, which electrically couple the above-mentioned primary electric motor 16 to actuators 20 which are to be operated on board the sailboat 100, e.g. to winches 21 and/or hydraulic actuators 22 (e.g., a rotary hydraulic pump).

**[0028]** As shown schematically, a single human-operated driving element 12 can be coupled to a number of actuators 20, winches 21 and/or hydraulic actuators 22, by a suitable arrangement of the electrical circuit 18 and in particular a suitable routing of the corresponding electrical cables 19.

**[0029]** According to one aspect of the present solution, the above mentioned actuators 20, winches 21 and/or hydraulic actuators 22 are provided with a respective secondary electric motor 24, configured to receive from the electrical circuit 18 the electrical energy generated by the primary electric motor 16 of the driving element 12 and transform this electrical energy into an actuation movement of the respective actuator 20, possibly via a suitable gear system 23 (for example, of the planetary gear type).

**[0030]** The actuation of each actuator 20 may, for example, be aimed at carrying out manoeuvres operated via lines (for example, to hoist, lower, or trim the sails 101 of the sailboat 100), and/or at carrying out manoeuvres operated via hydraulic pressure (for example, to manoeuvre a mast 102 or a foil of the same sailboat 100).

**[0031]** In a manner not shown in Figure 2, the electrical circuit 18 of the by-wire actuation system 10 may comprise appropriate switching elements (or "switches"), to selectively direct the electrical energy towards one or more of the actuators 20, winches 21 and/or hydraulic actuators 22, coupled to each driving element 12, for example, depending on commands given by an operator via an appropriate interface element, such as a control panel or an appropriate arrangement of push buttons or similar interface elements (not shown here).

**[0032]** The by-wire actuation system 10 further comprises a control unit 30, which is coupled to the aforementioned electrical circuit 18, primary electric motors 16 and secondary electric motors 24, and is configured to supervise and control the operation of the same by-wire actuation system 10, as will be described in more detail below.

**[0033]** The described by-wire actuation system 10 therefore advantageously allows to physically disconnect the mechanical transmission between the human-operated driving elements 12 (e.g., the cranks 14) and the actuators 20 (e.g., the winches 21 and/or hydraulic actuators 22), by removing the mechanical transmission members and replacing them with cables and electrical circuits.

**[0034]** This by-wire actuation system 10 enables appropriate control logics to be implemented by the control unit 30, for example, to optimize the power developed (in terms of rotational speed and torque) as a function of multiple operating parameters.

**[0035]** Furthermore, as will also be described below, the human-operated driving elements 12, being virtually "decoupled" from the actuators 20, i.e., from the winches 21 and/or the hydraulic actuators 22, can also be used for other purposes, for example to produce, via the corresponding primary electric motor 16, electrical energy to be stored in an energy storage system (including, for example, a battery) installed on board the sailboat 100.

**[0036]** The same energy storage system, at least under certain operating conditions, may allow to implement a servo-assistance for the aforementioned operation of the actuators 20.

**[0037]** Furthermore, advantageously, the by-wire actuation system 10 can be associated with energy recovery functions, for example, by using energy produced autonomously by the actuators 20 under certain operating conditions, for example by the winches 21 during operations which involve lowering or slacking the sails, or by the hydraulic actuators 22 in the case of operations involving the autonomous generation of energy in the associated hydraulic circuit.

**[0038]** Advantageously, the recovered energy can be used, for example, for recharging the energy storage system or for other uses on board the sailboat 100.

**[0039]** The by-wire actuation system 10 described herein therefore allows the following benefits to be achieved:

an improvement in efficiency, since removing the mechanical transmission allows efficiency to be gained and consequently less energy to be dissipated into heat;

an increase in layout freedom, since the electric cables 19, being flexible, can be positioned and routed in any suitable manner, for example allowing the positioning of the pedestal 15 and the winches 21 and/or the hydraulic actuators 22 in any desired position in the sailboat 100 (generally allowing opti-

mization of the positioning and space occupation); greater freedom and possibility of control, as the absence of mechanical constraints allows advanced control strategies to be implemented (e.g., any variable transmission ratio between the exerted mechanical power and the actuation speed); the possibility of additional functionalities, since the energy generated by human operation (e.g. by the crew grinders), or by the same actuators 20 in the recovery phase, can be used to recharge energy storage systems, and/or the same energy storage systems may allow additional functionalities to be implemented (such as, for example, adjustment of the sails with reduced or no human effort during a cruising navigation phase of the sailboat 100, outside of a racing or competition condition); easy actuation of a same actuator 20 by several different driving elements 12, since the sum of the power in this case occurs at an electrical level, eliminating the need to introduce, for example, a same torque into a mechanical transmission system in order to effectively actuate the same actuator.

**[0040]** With reference to Figure 3, a possible embodiment of the by-wire actuation system 10 is now described in greater detail.

**[0041]** As mentioned above, this by-wire actuation system 10 comprises a certain number N (with  $N \geq 1$ ) of human-operated driving elements 12 (of which Figure 3 shows only one for simplicity), which receive as an input the mechanical power exerted by the crew operators, for example, by means of cranks 14 carried by a pedestal 15 (each human-operated driving element 12 being able to have at least one crank 14, typically a pair of cranks 14, as human power input).

**[0042]** Each driving element 12 comprises: a respective primary electric motor 16; a mechanical coupling element 31 between the primary electric motor 16 and the crank(s) 14, e.g. represented by a 90° joint; and a reduction element 32, for example of the planetary gear type, coupled between the above-mentioned mechanical coupling element 31 and the primary electric motor 16 and configured to vary a reduction ratio for power transmission (e.g., between two or more selectable reduction ratios, one of which may provide for a unitary reduction ratio and at least another of which may provide for a reduction ratio greater than one, e.g., 1:3, 1:5, or 1:10).

**[0043]** The driving element 12 further comprises an inverter 34, electrically coupled to the primary electric motor 16 and interposed between the same primary electric motor 16 and the electrical circuit 18. In a per se known manner, the inverter 34 is designed to manage the electrical energy fed by the primary electric motor 16 into the electrical circuit 18, for example by means of suitable DC to AC conversions (or vice versa).

**[0044]** In addition, the inverter 34 comprises a respective controller 34', for example provided by a microcontroller, microprocessor or similar digital processing ele-

ment, configured to control the operation of the inverter 34 and, in general, of the primary electric motor 16.

**[0045]** The inverter 34 and the controller 34' may optionally be integrated into the respective primary electric motor 16.

**[0046]** A switch box, indicated by 36, selectively couples the output of each driving element 12 (in particular, the output of the corresponding inverter 34) to one or more (optionally to each one) of the actuators 20 of the by-wire actuation system 10 (only two of these actuators 20 are shown for simplicity in Figure 3), via an electrical bus 35 of the electrical circuit 18, particularly a current bus.

**[0047]** Each of the above mentioned actuators 20 (in a number M, with  $M \geq 1$ ), for example winches 21 and/or hydraulic actuators 22 (for example of the pump type), comprises: a respective inverter 37, coupled to the electrical bus 35 so as to receive the electrical energy supplied by one or more of the driving elements 12 and designed to manage this electrical energy, for example by means of appropriate AC to DC conversions (or vice versa); a respective secondary electric motor 24 connected to the output of the inverter 37; and a respective reduction element 38, for example of the planetary gear type, coupled to the output of the secondary electric motor 24 and configured to vary a reduction ratio for power transmission to be applied for the execution of the manoeuvres (which can for example be operated via a line in the case of winches 21 or via a hydraulic circuit in the case of hydraulic actuators 22).

**[0048]** As previously discussed, the inverter 37 is associated with a respective controller 37', for example provided by a microcontroller, microprocessor or similar digital processing element, configured to control the operation of the inverter 37 and of the secondary electric motor 24.

**[0049]** The inverter 37 and the controller 37' may optionally be integrated into the respective secondary electric motor 24.

**[0050]** The by-wire actuation system 10 also comprises a control node 39, for example of the CAN (Controller Area Network) type, coupled to the controllers 37' of the primary and secondary electric motors 16, 24 and also coupled in communication, e.g. via a CAN communication line, with a control and management unit of the sailboat 100 (not shown here), referred to as BCU (Boat Control Unit) 40, configured to control and manage the general operation of the same sailboat 100, in a known manner and therefore not described in detail herein.

**[0051]** In the embodiment shown, a capacitor element 41, having a storage capacitance, is also coupled to the electric bus 35 (in particular, having a first terminal coupled to the electric bus 35 and a second terminal coupled to a reference, or ground GND terminal).

**[0052]** Purely by way of example, Figure 4 shows a possible connection diagram in the by-wire actuation system 10, in this case between four driving elements 12 (referred to as A-D), of the pedestal type 15, carrying a

pair of cranks 14, and four actuators 20, in particular three winches 21 (referred to as A'-C') and one hydraulic actuator 22 (referred to as D'). The same Figure 4 shows the electric bus 35 to which the driving elements 12 and the actuators 20 are coupled, via the switching assembly 36, with the associated capacitor element 41, having the corresponding storage capacitance.

**[0053]** As shown in this Figure 4, each driving element 12 can be associated with a respective user interface element 49, for example implemented via a physical button or panel, to implement the connection with a corresponding actuator 20 (a connection that is implemented via the control unit 30, not shown here, controlling the above-mentioned switching assembly 36).

**[0054]** In the event that several driving elements 12 select the same actuator 20 (for example the same winch 21), these driving elements 12 add up the power exerted and divide a related force feedback (as will be described below). Moreover, different driving elements 12 can actuate different actuators 20 to be able to work on different manoeuvres simultaneously.

**[0055]** A control mode that can be implemented by the control unit 30 can also be selected from the user interface (as will be described in detail below).

**[0056]** In a further embodiment, shown in Figure 5, the by-wire actuation system 10 may comprise an energy storage unit 42 (including, for example, a battery or battery pack, for example with a 48 V voltage output) installed on board the sailboat 100, which can be selectively connected to the electrical circuit 18 via the same switching assembly 36.

**[0057]** This energy storage unit 42 may be coupled, in a known manner, not described in detail herein, to energy recovery systems that may be present on the sailboat 100 (e.g., solar panels, wind systems, or hydrogenerators).

**[0058]** In addition, a current sensing/interruption element 43 is interposed between the output of this energy storage unit 42 and the switching assembly 36, in order to sense the electrical current flow and possibly interrupt this flow (acting as an electrical fuse).

**[0059]** In this embodiment, the electrical circuit 18 is precharged and maintained at a nominal operating voltage by the energy storage unit 42.

**[0060]** Furthermore, in this implementation, the current sensing/interruption element 43 allows to demonstrate, in the case of a race or other type of competition, the legality of the manoeuvres, i.e., that the same manoeuvres are carried out exclusively with human energy (as required by the competition regulations).

**[0061]** On the contrary, on cruising or in any case outside of racing conditions, it is possible to implement a servo-assistance for the same manoeuvres, with energy coming from the aforementioned energy storage unit 42, produced for example by the recovery systems (therefore, being a non-human originated energy).

**[0062]** In general, in both embodiments described, the above-mentioned control node 39 implements, in cooperation with the BCU 40 and with the controllers 34', 37' of

the primary and secondary electric motors 16, 24, the control unit 30 of the by-wire actuation system 10, which is coupled to the switching assembly 36 to manage the connections between the driving elements 12 and the loads (i.e., the actuators 20) in accordance with appropriate control strategies.

**[0063]** In particular, this control unit 30 is configured to control the operation of the above-mentioned primary and secondary electric motors 16, 24 by means of an appropriate control which can alternatively be a voltage, torque or speed control.

**[0064]** In general, this control can be based on the quantities that are now listed, in relation to each subsystem making up the aforementioned by-wire actuation system 10.

**[0065]** With regard to the driving elements 12, the input variables for the control may comprise the torque  $T_{HAN,PED}$  developed by the cranks 14, and the speed  $S_{HAN,PED}$  of the same cranks 14 (which are a function of the effort of the crew operators and are also affected by a resistance torque  $T_{EM,PED}$  which can be applied by the corresponding primary electric motor 16 on the same cranks 14); and also an indication of a speed change (depending for example on the activation of the push button or similar user interface element 49 by the crew). The output variables may comprise the above-mentioned resistance torque  $T_{EM,PED}$  applied by the primary electric motor 16 (which, in turn, is a function of a torque acting on the load, caused, for example, in the case of the winches 21, by the resistance of the respective lines), the rotation speed  $S_{EM,PED}$  of the corresponding primary electric motor 16 (which is a function of the speed  $S_{HAN,PED}$  of the cranks 14), and the electric voltage  $V_{EM,PED}$  developed by the primary electric motor 16 (which is affected by the resistance torque  $T_{EM,PED}$ ).

**[0066]** In general, for the driving elements 12, the following relation applies to the output power generated:

$$P_{PED} = T_{HAN,PED} * S_{HAN,PED} .$$

**[0067]** As regards the actuators 20, and in particular the winches 21, the input variables can comprise the torque and speed  $T_{EM,PED}$ ,  $S_{EM,PED}$  developed by the primary electric motor 16 of the driving element 12 with which they are associated (in the case of multiple driving elements 12 coupled to the same actuator 20, one of them may be considered as primary or "master" determining the aforementioned torque and speed values), the power  $P_{EM,PED}$  developed by the primary electric motors 16 of the driving elements 12 with which they are associated; the output variables may comprise the torque  $T_{EM,WIN}$  of the respective secondary electric motor 24 (which is a function of the torque  $T_{WIN}$  on the same winch 21 and also of the torque generated by the driving element 12), the speed  $S_{EM,WIN}$  of the respective secondary electric motor 24 (which is a function of the speed  $S_{HAN,PED}$  of the associated cranks 14 and of the afore-

mentioned generated power  $P_{PED}$ ), the direction of rotation of the secondary electric motor 24 (which is a function of the above-mentioned speed change indication).

**[0068]** Similar considerations can be made with regard to the input/output variables relating to a hydraulic actuator 22 in the by-wire actuation system 10 described in detail above.

**[0069]** The power generated by the actuators 20 is determined by the power generated by the driving elements 12 associated therewith (in a number equal to  $K_{PED}$ ), considering an efficiency ratio  $\eta_{PED}$ :  $P_{WIN} = K_{PED} * P_{PED} * \eta_{PED}$ .

**[0070]** In general, as shown schematically in Figure 6, the control logic implemented by the control unit 30 in the by-wire actuation system 10 provides that, depending on the input on the driving elements 12 (for example, in terms of torque  $T_{HAN,PED}$  and speed  $S_{HAN,PED}$  developed by the cranks 14), a consequent actuation of the actuators 20 is generated (for example, in terms of torque  $T_{WIN}$  and speed  $S_{WIN}$  of the winch 21, or of torque  $T_{PUMP}$  and speed  $S_{PUMP}$  of the hydraulic actuator 22).

**[0071]** In addition, the control logic provides appropriate feedback so that the crew operators can have feedback on the actuation, perceive how much load is present, for example in order to timely realize any anomalies, given the lack of a traditional force feedback guaranteed by a mechanical transmission. In the case of operating the winches 21 in conditions of poor visibility, for example at night, it is important that the crew operators can have this feedback on the actuation.

**[0072]** In the case of the by-wire actuation system 10, this feedback can be recreated virtually in several ways: through a force feedback on the driving elements 12 (for example on the cranks 14 of the pedestal 15), optionally appropriately geared down (in particular, this force feedback can be implemented via the torque  $T_{EM,PED}$  generated by the relevant primary electric motor 16); through a tactile feedback via vibration on the same driving elements 12; through a visual feedback; through an audible feedback.

**[0073]** A number of possible control strategies that can be implemented by the control unit 30, via the controllers 34', 37' of the primary and secondary electric motors 16, 24, are now summarized. These control strategies may, for example, be implemented based on commands given by the crew operator via the user interface elements 49.

**[0074]** In a fixed ratio mode, the speed ratio between the driving elements 12 and the actuators 20 is imposed, being selectable from a set of discrete ratios, by the aforementioned user interface.

**[0075]** In a variable ratio mode (similar to a CVT - Continuously Variable Transmission - control), the speed ratio can be varied continuously, for example, with the aim of maximising each time the speed of the actuator 20 depending on the load.

**[0076]** These fixed ratio or variable ratio modes can be implemented in racing or competition conditions and are generally subject to the (isopower) condition that the

power generated by the actuators 20 is equal to the power generated by the driving elements 12 associated therewith, considering the efficiency ratio (essentially, the power available for the actuators 20 cannot exceed the generated human power).

**[0077]** Furthermore, a servo-assisted mode can be implemented, in particular in cruising (not racing or competition) conditions, which provides the possibility of assisting the human power provided by the crew operators through the driving elements 12 with an assistance power produced by recovery systems; as mentioned above, the assistance power can be provided from the energy storage unit 42 (including the battery).

**[0078]** Moreover, a recharging mode can be implemented by the aforementioned energy storage unit 42, which also can be used outside racing or competition situations, for example in energy shortage situations (in the event that the above-mentioned recovery systems, for example due to environmental conditions or other reasons, are unable to meet the energy demand). In this case, the power produced by the crew using the driving elements 12 may be stored in the energy storage unit 42, which will recharge the respective battery.

**[0079]** In addition, as indicated above, the energy possibly produced autonomously by the actuators 20 can also be used, with energy recovery functionality, for recharging the aforementioned energy storage unit 42, or in any case for different operations on board the sailboat 100.

**[0080]** With reference to the block diagram in Figure 7 and the diagrams in Figures 8A-8C, a possible scheme of operation of the by-wire actuation system 10 is now described in greater detail (with reference to an implementation without energy storage unit 42).

**[0081]** Initially, stage 50, the system is turned off, awaiting intervention by the crew operators on the driving elements 12.

**[0082]** This intervention takes place at stage 51, for example by actuating the cranks 14 associated with one or more pedestals 15 (resulting in an increase in the speed  $S_{HAN,PED}$  of the same cranks 14).

**[0083]** This actuation involves charging of the storage capacitance of the capacitor element 41, resulting in an increase in the voltage at its terminals, and therefore in the voltage  $V_{BUS}$  on the electric bus 35, as indicated in stage 52.

**[0084]** As soon as this voltage reaches a nominal voltage ( $V_{nom}$ ), the power transmission (in by-wire mode) between the driving elements 12 and the respective actuators 20 is activated, in stage 54, for example with the actuation of a related winch 21, whose speed  $S_{WIN}$  and torque  $T_{WIN}$  increase until they reach a suitable value determined by the control logic.

**[0085]** As mentioned above, these values are in general (necessarily in racing conditions) a function of the human action exerted by the crew.

**[0086]** As shown in stage 55a, the drive control logic, implemented, as discussed above, by the control unit 30,

may provide a closed-loop control of the voltage  $V_{BUS}$  on the electrical bus 35, for example with an effect on the resistance torque  $T_{EM,PED}$  applied to the driving elements 12 by the corresponding primary electric motors 16.

**[0087]** According to a possible aspect of the present solution, this resistance torque can advantageously be such as to keep the crew operator (e.g., the grinder in the case of a racing or competition) within a speed range where there is greater biomechanical efficiency (thus implementing a maximum efficiency pursuit logic). In this regard, for example, this maximum efficiency is known to be provided at a rotation speed of the cranks 14 of around 80 revolutions per minute (rpm).

**[0088]** As indicated in stage 55b, alternatively, the above control logic may provide a closed-loop control of the speed and/or torque of the secondary electric motor 24 of the above-mentioned actuators 20 (winches 21 and/or hydraulic actuators 22), as a function of the human input from the crew.

**[0089]** As a further alternative, indicated in stage 55c, the control logic may provide a control of the direction of rotation of the same secondary electric motor 24 of the actuators 20, in particular of the winches 21, to implement a related mechanical gear shift.

**[0090]** The advantages enabled by the present solution are clear from the foregoing.

**[0091]** In any case, it is again emphasized that the by-wire actuation system 10 allows, compared to traditional solutions based on a mechanical transmission system, an improvement in efficiency, an increase in layout freedom, greater freedom and possibility of control, with the possibility of implementing additional functionalities, given that, for example, human energy or the energy generated by the same actuators in a recovery phase can be used to recharge energy storage systems and/or implement servo-assistance functionalities.

**[0092]** Moreover, it is clear that modifications and variations may be made to the above description without however departing from the scope defined by the claims.

**[0093]** In particular, it is underlined that the by-wire actuation system 10 can be advantageously implemented for any type of boat, for the actuation of any number and type of actuators, even different from the winches and hydraulic actuators specifically referred to above, for example, windlasses, capstans, anchors, or any other system on the boat that requires an actuation.

## Claims

1. An actuation system (10) for actuating actuators in a sailboat (100), comprising, on board the sailboat (100):

one or more driving elements (12), operable by crew operators;

one or more actuators (20), configured to be

- driven by said driving elements (12),  
 wherein said driving elements (12) are provided  
 with a respective primary electric motor (16) and  
 said actuators (20) are provided with a respec-  
 tive secondary electric motor (24),  
 further comprising an electrical circuit (18), con-  
 figured to electrically couple said primary elec-  
 tric motor (16) and secondary electric motor  
 (24),  
 wherein said primary electric motor (16) is con-  
 figured to transform a driving motion of the re-  
 spective of said driving elements (12) into elec-  
 tric energy in said electrical circuit (18); and said  
 secondary electric motor (24) is configured to  
 transform electric energy in said electrical circuit  
 (18) into an actuating motion of the respective  
 actuator (20).
2. The actuation system according to claim 1, of the by-  
 wire type, wherein said driving elements (12) are  
 mechanically disconnected from said actuators (20).
  3. The system according to claim 1 or 2, wherein said  
 actuators (20) comprise one or more of winches (21)  
 and hydraulic actuators (22).
  4. The system according to any one of the preceding  
 claims, comprising a control unit (30) coupled to said  
 electric circuit (18), primary electric motors (16) and  
 secondary electric motors (24), configured to super-  
 vise and control the operation of the actuation sys-  
 tem (10).
  5. The system according to claim 4, wherein said con-  
 trol unit (30) is configured to implement an energy  
 recovery function, using energy produced by the  
 actuators (20), under certain operating conditions.
  6. The system according to claim 4 or 5, wherein said  
 control unit (30) is configured to generate and pro-  
 vide to said crew operators a feedback indicative of a  
 load on said actuators (20), said feedback being  
 generated virtually by one or more of: a force feed-  
 back; a tactile feedback; a visual feedback; and an  
 audible feedback.
  7. The system according to claim 6, wherein said con-  
 trol unit (30) is configured to implement said force  
 feedback as a resisting torque ( $T_{EM,PED}$ ) on the  
 driving elements (12) generated by the correspond-  
 ing primary electric motor (16), such that the driving  
 motion by said crew operators is maintained in an  
 operating range of optimized biomechanical effi-  
 ciency.
  8. The system according to any one of claims 4-7,  
 wherein said control unit (30) comprises respective  
 controllers (34', 37') of said primary and secondary  
 electric motors (16, 24) and a control node (39),  
 coupled to said controllers (34', 37') and further con-  
 figured to be coupled in communication with a control  
 and management unit (40) of the sailboat (100).
  9. The system according to any one of claims 4-8,  
 wherein said control unit (30) is configured to gen-  
 erate a driving torque for said actuators (20) accord-  
 ing to a fixed selectable ratio, or a continuously  
 variable ratio, between the speed of said driving  
 elements (12) and the speed of said actuators (20).
  10. The system according to any one of claims 4-9,  
 further comprising an energy storage unit (42) in-  
 stalled on-board the sailboat (100), selectively con-  
 nectable to the electrical circuit (18); wherein, under  
 certain operating conditions, said control unit (30) is  
 configured to implement a recharging of said energy  
 storage unit (42) using energy associated with the  
 movement of said driving elements (12).
  11. The system according to claim 10, wherein said  
 control unit (30) is configured to implement a ser-  
 vo-assistance for the operation of said driving ele-  
 ments (12) by said crew operators, from energy  
 stored in said energy storage unit (42).
  12. The system according to claim 10 or 11, wherein said  
 energy storage unit (42) is coupled to said electrical  
 circuit (18) via a current sensing element (43) inter-  
 posed between the output of said energy storage unit  
 (42) and said electrical circuit (18); said current  
 sensing element (43) being further controlled to in-  
 terrupt a current flow between said energy storage  
 unit (42) and said electrical circuit (18).
  13. The system according to any one of claims 4-12,  
 comprising a switching assembly (36), configured to  
 be controlled by said control unit (30) so as to selec-  
 tively couple an output of each of the driving ele-  
 ments (12) to one or more of the actuators (20) via an  
 electrical bus (35) of said electrical circuit (18);  
 further comprising a human interface (49) operable  
 by said crew operators; wherein said control unit (30)  
 is coupled to said human interface (49) to implement  
 the control of said switching assembly (36).
  14. The system according to any one of the preceding  
 claims, wherein said control unit (30) is coupled to  
 said driving elements (12) via flexible electrical  
 cables (19) of said electrical circuit (18).
  15. The system according to any one of the preceding  
 claims, wherein said driving elements (12) comprise  
 one or more cranks (14) carried by a pedestal (15),  
 having a base solidly coupled to said sailboat (100).
  16. A sailboat (100), comprising the actuation system

(10) according to any one of the preceding claims.

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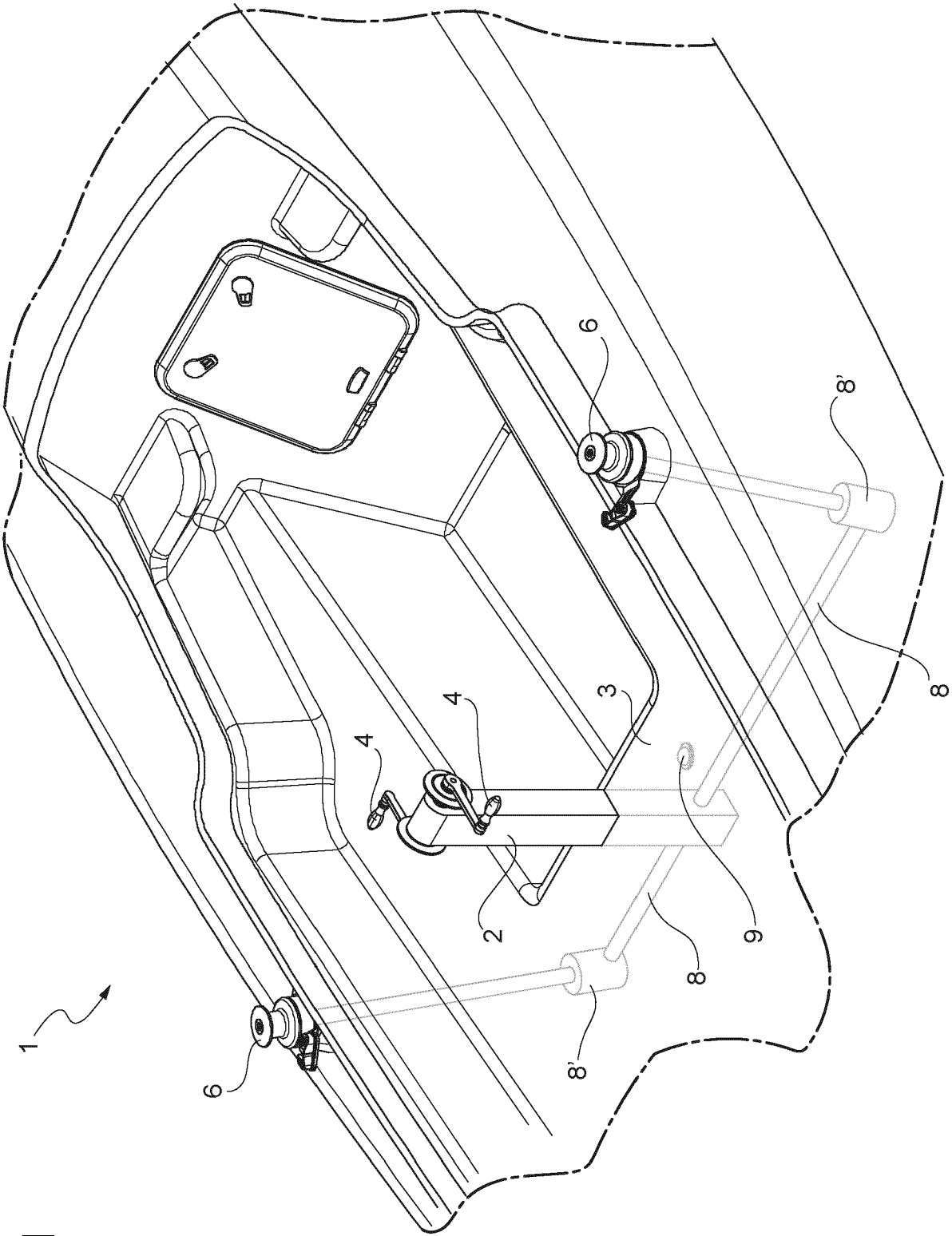


FIG. 1

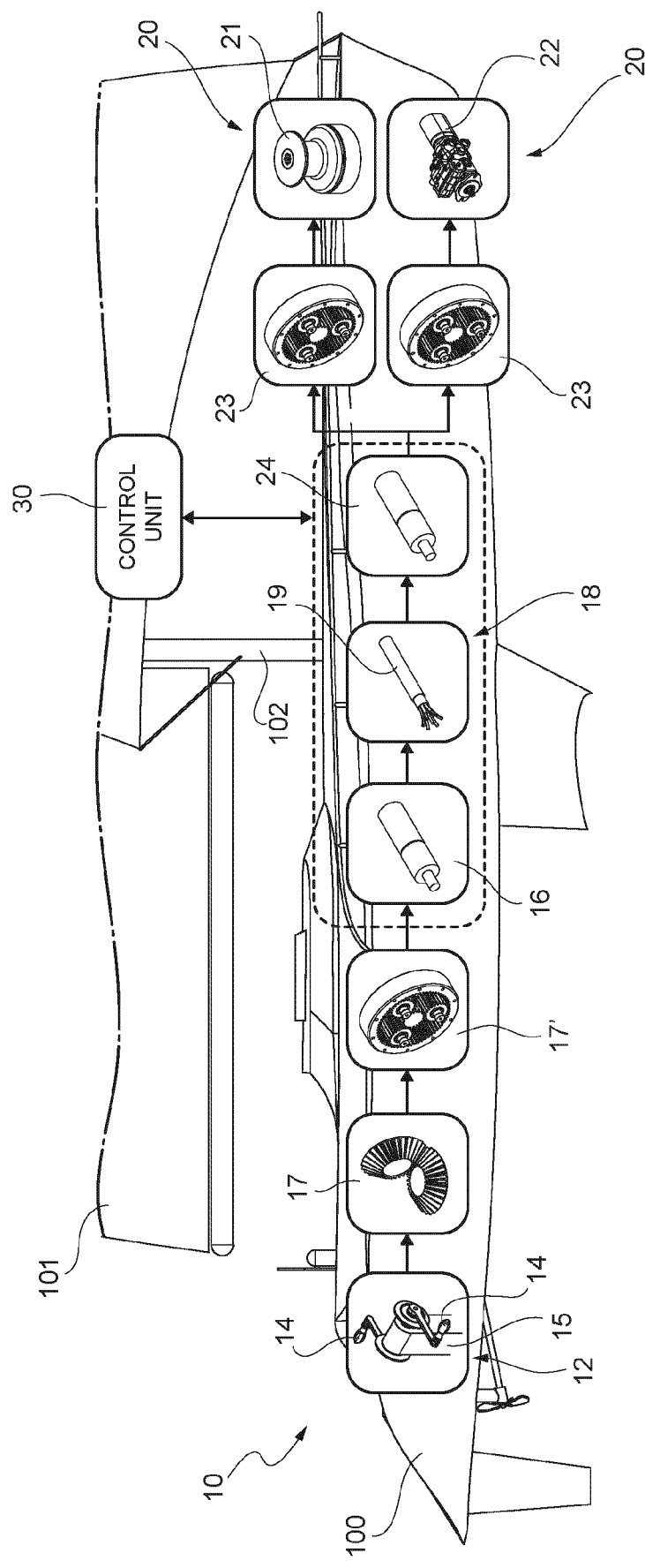


FIG. 2

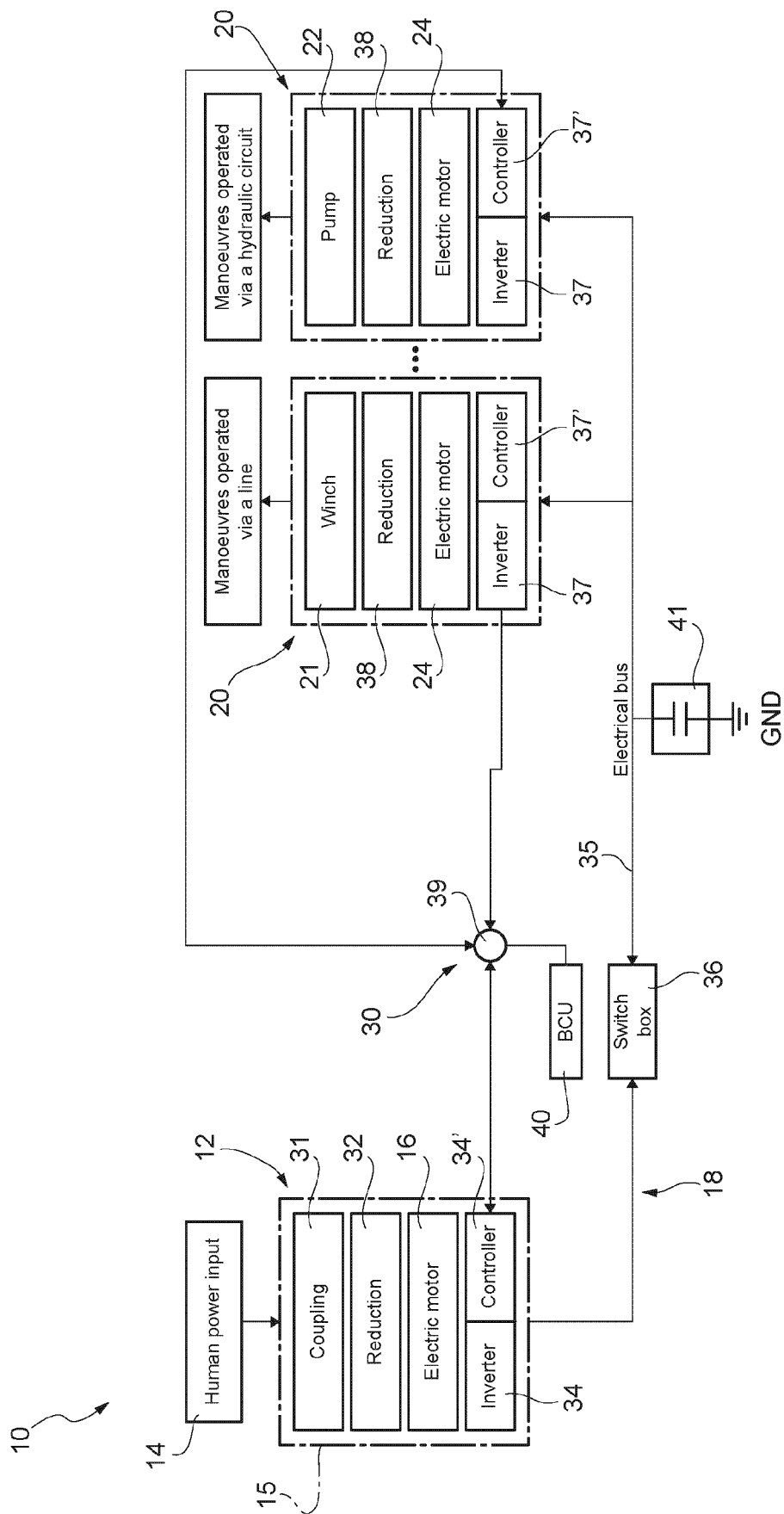


FIG. 3

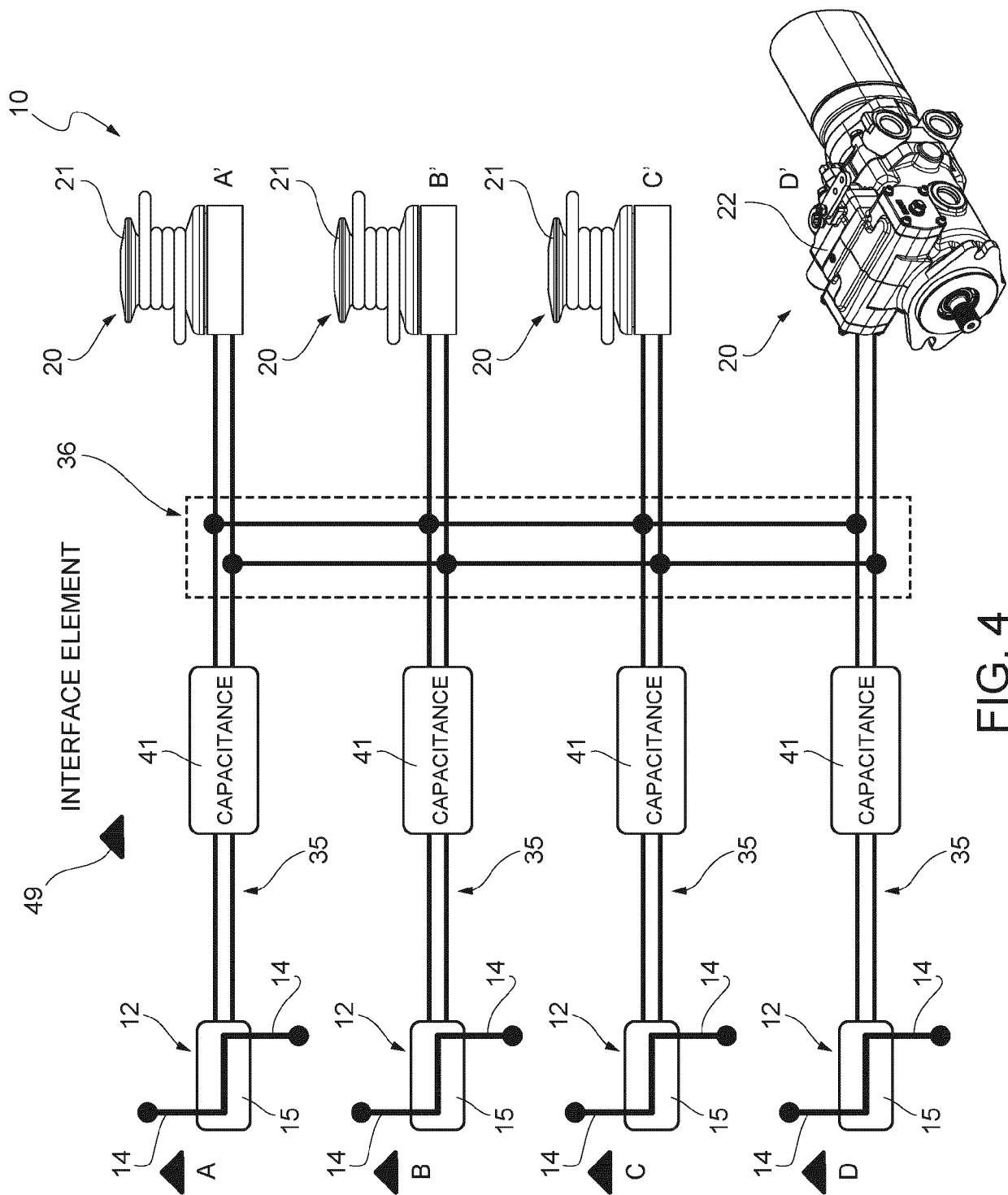


FIG. 4

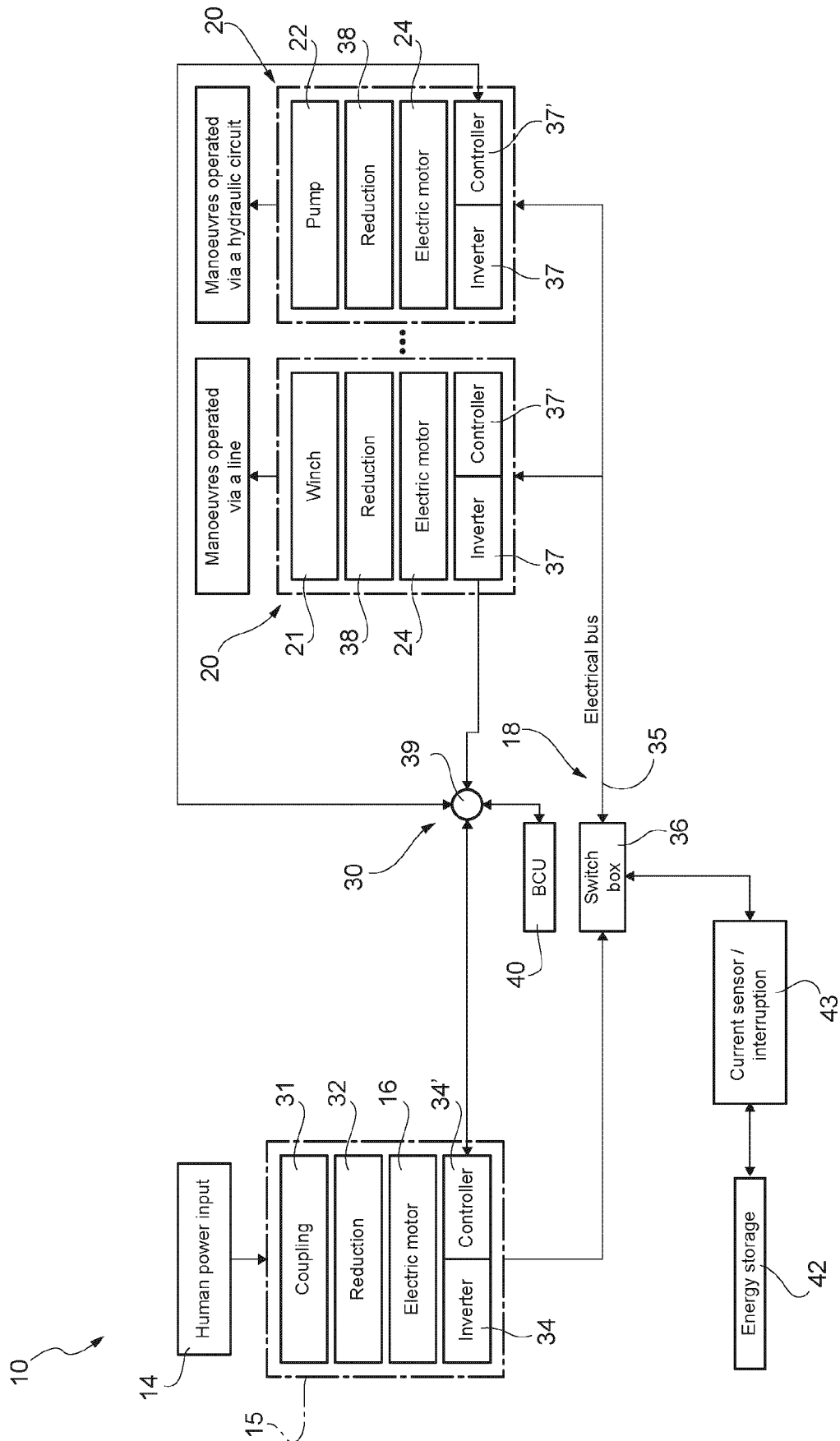


FIG. 5

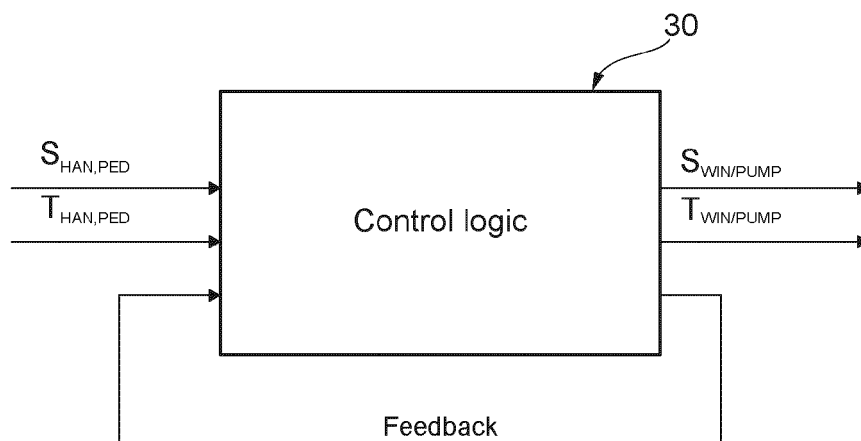


FIG. 6

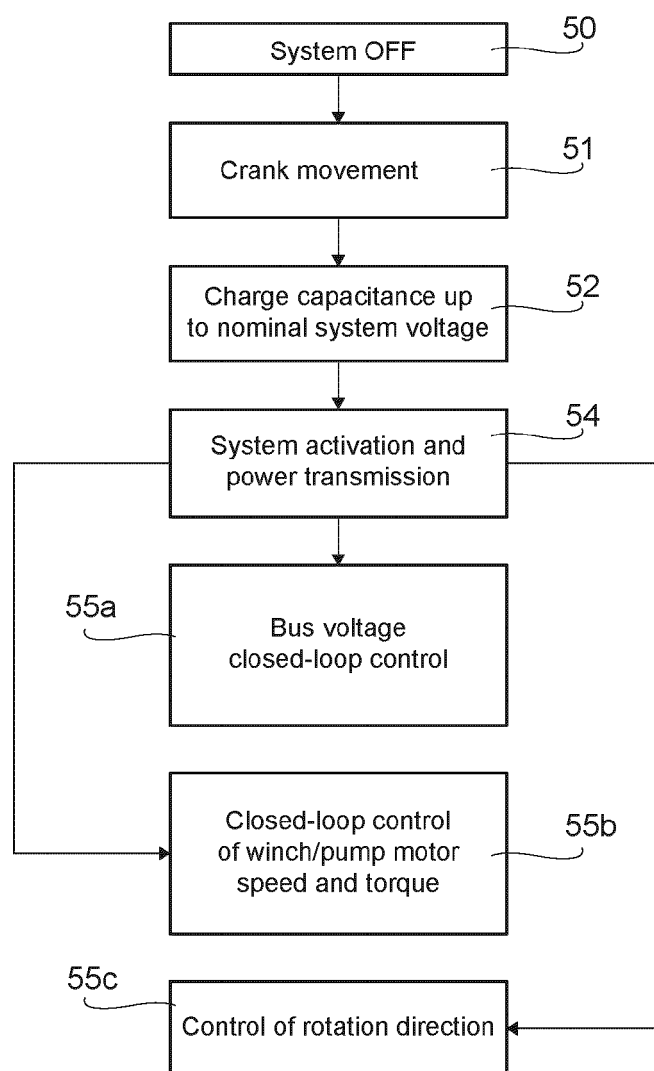


FIG. 7

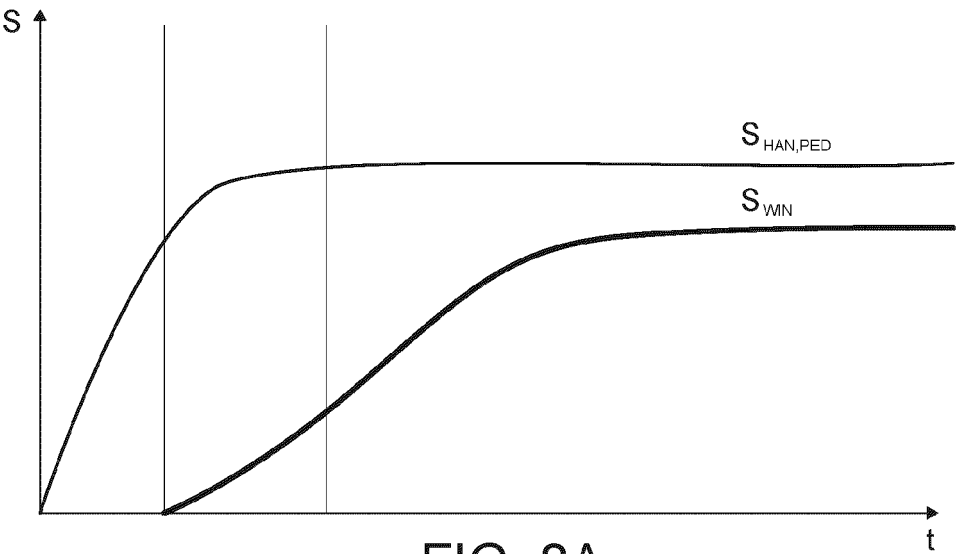


FIG. 8A

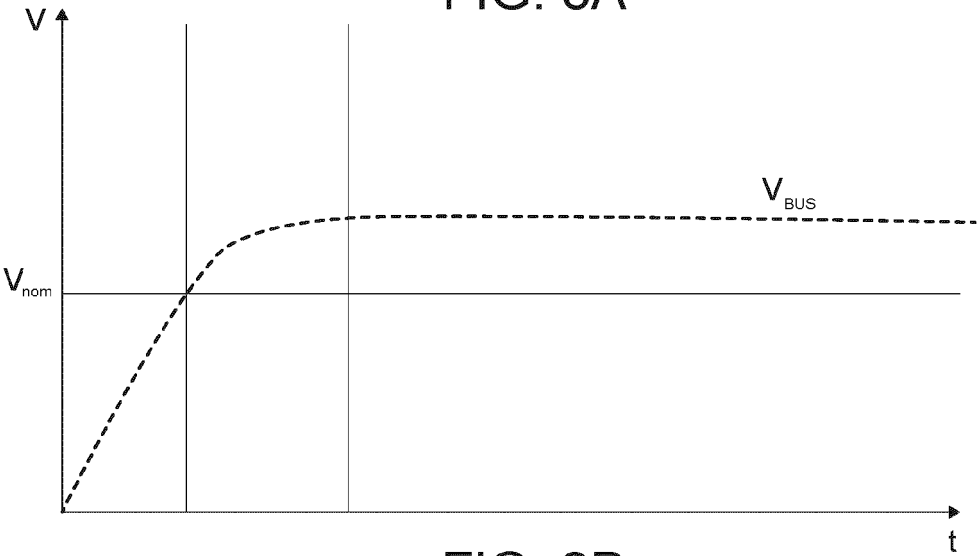


FIG. 8B

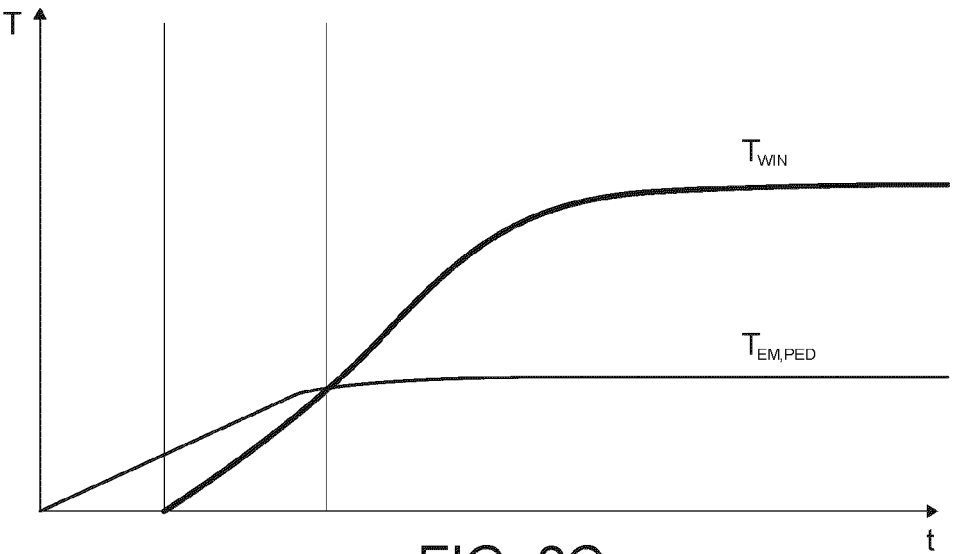


FIG. 8C



## EUROPEAN SEARCH REPORT

Application Number

EP 24 19 5534

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| Category                                                                                                                                                                                                                                                                     | Citation of document with indication, where appropriate, of relevant passages                                                                             | Relevant to claim                | CLASSIFICATION OF THE APPLICATION (IPC)  |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------|------------------------------------------|
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| The present search report has been drawn up for all claims                                                                                                                                                                                                                   |                                                                                                                                                           |                                  |                                          |
| Place of search                                                                                                                                                                                                                                                              |                                                                                                                                                           | Date of completion of the search | Examiner                                 |
| The Hague                                                                                                                                                                                                                                                                    |                                                                                                                                                           | 17 October 2024                  | Gardel, Antony                           |
| CATEGORY OF CITED DOCUMENTS                                                                                                                                                                                                                                                  |                                                                                                                                                           |                                  |                                          |
| X : particularly relevant if taken alone<br>Y : particularly relevant if combined with another document of the same category<br>A : technological background<br>O : non-written disclosure<br>P : intermediate document                                                      |                                                                                                                                                           |                                  |                                          |
| T : theory or principle underlying the invention<br>E : earlier patent document, but published on, or after the filing date<br>D : document cited in the application<br>L : document cited for other reasons<br>& : member of the same patent family, corresponding document |                                                                                                                                                           |                                  |                                          |

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