

Redundant electric rudder installation for a submarine, and operation of said installation

5 The invention relates to a rudder installation, in particular for a submarine, the rudder installation being designed to electrically actuate the rudders. The rudder installation is of redundant design, which means that at least reliable resurfacing is possible.

10 Increasingly, there is an interest in also designing the rudder installation of submarines to be electrical. With submarines, however, there is the challenge that there needs to be functionality even in the event of a partial failure, since the rudders are required in order to get to the water's surface under the submarine's own drive power. There is therefore still a certain amount of scepticism regarding the possible vulnerability of an electric rudder installation and the tendency to resort to tried-and-tested technologies, for example a hydraulic rudder installation.

15 Conventionally, submarines have a cross-type rudder arrangement. This allows a vertical rudder to be used to steer to port and starboard. The two rudders arranged horizontally can be used to change depth or to impart a rolling movement on the submarine. The result of this is that the actuation for the desired change of direction can easily be transmitted to the rudders. Newer boats increasingly also use an X-type rudder arrangement, however, in which all four rudders run diagonally with respect to the horizontal. The advantage is that this means that all the rudders are always involved in the change of direction, as a result of which said change of direction can be performed more quickly, that is to say that the submarine is more maneuverable. On the other hand, 25 it makes actuation of the rudders more complex.

The subsequently published DE 10 2021 211 387 discloses a pressure-resistant piston media separator, in particular for a linear drive of a ship's steering gear.

30 DE 10 2016 006 933 B3 discloses a method for compensating for the blockage of a rudder blade in an X-type rudder.

DE 10 2016 204 248 A1 discloses a linear drive for a ship's steering gear.

DE 10 2021 211 387 A1 discloses a pressure-resistant piston media separator, a linear drive for a ship's steering gear and a submarine therewith.

- 5 Linke, Petra and Frank Weidemann, "Einführung in die Konstruktionsmethodik", Handbuch Maschinenbau, Wiesbaden, Springer Fachmedien Wiesbaden, 2021, 677, 692-93, Web, discloses an introduction to design methodology.

US 2018 / 0050783 A1 discloses a control apparatus.

10

It is the object of the invention to provide an electrically adequate redundant rudder installation so that it can be employed in particular on a submarine.

15

This object is achieved by an electric rudder installation having the features specified in claim 1, a submarine having the features specified in claim 14 and the method having the features specified in claim 15. Advantageous developments emerge from the subclaims, the description that follows and the drawing.

20

The electric rudder installation according to the invention has at least three rudders. A cross-type rudder requires only three rudders. An X-type rudder has four rudders. Additionally, two further depth rudders are often arranged on the bow or tower. Three, four, five or six rudders are therefore customary. A moving rudder or rudder blade for the purposes of the invention is therefore the respective individual moving rudder; the full complement of all the rudders with the engineering required for actuation forms the entire rudder installation. In the case of a surface vessel, a single rudder may already be adequate, but it may also have two or more rudders, which are usually arranged parallel beside one another. At least three rudders are required for a submarine having a cross-type rudder. Each rudder has at least one first electric servomotor. If multiple rudders are present, multiple first electric servomotors are also present. The first electric servomotor can be used to position the respective connected rudder at the rudder angle. This means that the entire transmission of a control signal takes place electrically and therefore by way of simple cabling. The servomotor and the rudder may be operatively connected directly or indirectly by way of mechanical elements. The rudder installation has at least

30

one control console, a first rudder control system and a first motor controller. The control console is designed to input control commands. In particular, the control commands can be input by a user. The control commands are preferably in a form such that they correspond to the change of direction of travel that is input, for example. The control console and the first rudder control system are connected to transmit the control commands. The first rudder control system is designed to process the control commands and to ascertain actuation commands. In particular, the individual rudder angles are computed from the control commands and the actuation commands for the individual electric servomotors are computed from the rudder angles to be attained. The first rudder control system and the first motor controller are connected to transmit the actuation commands. The first motor controller is electrically connected to the first servomotors to position the rudders in accordance with the actuation commands. This connection can be made for example by directly actuating the first servomotors by changing or adjusting the motor currents, that is to say for example by directly providing the voltage for moving the first servomotors. This is therefore an electric rudder installation.

According to the invention, the rudder installation has at least one second rudder control system. The first rudder control system and the second rudder control system are therefore separate from one another, even if they may be integrated in a common housing, for example. An essential aspect is that the first rudder control system and the second rudder control system work completely independently of one another and therefore the second rudder control system is not impaired if the first rudder control system fails, and vice versa. The control console and the second rudder control system are connected to transmit the control commands. The second rudder control system is designed to process the control commands and actuation commands. The second rudder control system and the first motor controller are connected to transmit the actuation commands. By way of example and preferably, the first rudder control system is designed to monitor the second rudder control system and the second rudder control system is designed to monitor the first rudder control system. In this case, there can be provision for the first rudder control system to deliver its actuation commands to the first motor controller, while the second rudder control system likewise receives the inputs parallel to the first rudder control system, but does not output actuation commands. If the first rudder control system no longer outputs actuation commands, the system or the second rudder

control system detects a malfunction in the first rudder control system and outputs at least one error message. In particular, there can be provision for the second rudder control system to output actuation commands following detection of the malfunction. Furthermore, there can be provision for the first rudder control system to be shut down or
5 for the transmission of the actuation commands from the first rudder control system to the motor controller to be interrupted. Alternatively or additionally, by way of example, and preferably, the first rudder control system and the second rudder control system are manually selectable. It is thus possible to manually change over between the first rudder control system and the second rudder control system. In a further alternative, the second
10 rudder control system monitors the first rudder control system in the normal state. The two rudder control systems receive the same inputs from the control console, and the two control systems compute the corresponding rudder angles. The second rudder control system additionally receives the data produced by the first rudder control system and compares them with its own results. If they are identical, the second rudder control system
15 does nothing. If a variance is identified, a user is informed in order to select a rudder control system. If the first rudder control system fails, the second rudder control system receives no data from the first rudder control system and can thus automatically take on the tasks of the first rudder control system completely.

20 Especially in the case of a submarine, in particular in the case of a submarine having an X-type rudder, converting a control command into an actual change of angle for the rudders is complex. Whereas in the case of a surface vessel with just one rudder there is only the choice between starboard and port and the rudder is moved in the direction to be steered as appropriate, said rudder is much more complex for a submarine as a result
25 of the free movement in three directions, including a roll movement. Especially the redundant design of the rudder control system is therefore particularly advantageous.

In a further embodiment of the invention, the rudders have at least one second electric servomotor. The rudder installation also has a second motor controller. The first rudder
30 control system and/or second rudder control system and the second motor controller are connected to transmit the actuation commands. The second motor controller is connected to the second servomotors to position the rudders in accordance with the actuation commands. In this scenario, it is firstly possible for the first rudder control system to be

connected only to the first motor controller and for the second rudder control system to be connected only to the second motor controller. In this embodiment, two parallel and completely independent systems exist beside one another. Secondly, it is possible both for the first rudder control system to be connected both to the first motor controller and to the second motor controller and for the second rudder control system to be connected both to the first motor controller and to the second motor controller. In this case, the second rudder control system can effectively be kept on standby, for example, and engaged only if the first rudder control system fails. Alternatively, the second rudder control system can monitor the first rudder control system and automatically take over if said first rudder control system fails or, if there is a discrepancy between the two rudder control systems, can advise a user of the problem to allow manual selection of a rudder control system. This further increases the redundancy. The first rudder control system and/or second rudder control system are also connected to the first motor controller to transmit the actuation commands. The first motor controller is connected to the first electric servomotor and the second motor controller is connected to the second electric servomotor.

The respective first electric servomotor and the second electric servomotor each move a rudder, which means that the rudder can be positioned even if one of the servomotors fails. There can be provision for the first motor controller to be optionally also able to be connected to the second electric servomotor and for the second motor controller to be optionally able to be connected to the first electric servomotor.

A possible combination of the redundancy of the rudder control systems by way of a first rudder control system and a second rudder control system and the further redundancy with a first motor controller and a second motor controller, combined also with the redundant design of the servomotors, greatly improves the robustness of the overall system, in particular when choosing the possible embodiment that the two rudder control systems are each designed to actuate both motor controllers in each case.

In a further embodiment of the invention, the first motor controller and the second motor controller are combined in a housing. The first motor controller and the second motor controller may also effectively be in the form of a common motor controller, one subregion

being designed to actuate the first servomotors and a second subregion being designed to actuate the second servomotors.

5 In a further embodiment of the invention, the first electric servomotor and the second electric servomotor each provide only 50% to 95% of the power required for adjusting the respective rudder with maximum speed or maximum adjustment torque. Thus, although there is not complete redundancy if a servomotor fails, functionality persists. By way of example, at high speeds and when small turning circles are desired, the power may then no longer be adequate in this regard to move the rudder against the pressure at full speed, 10 which is possible only when both servomotors are functional. Control thus remains possible, albeit somewhat limited. On the other hand, the servomotors can be of much smaller design, which in turn saves space and weight.

15 In a further embodiment of the invention, the control console, the first rudder control system and the second rudder control system are combined in a housing. In particular, the first rudder control system and the second rudder control system may be integrated in the control console physically.

20 In a further embodiment of the invention, the rudder installation has six rudders, in particular an X-type rudder and two front depth rudders.

In a further embodiment of the invention, the rudder installation has a manual auxiliary control console. The manual control console is designed to input actuation commands. There can be provision for the manual auxiliary control console to be installed directly on 25 the motor controller, but it is preferably arranged directly adjacent to the control console. The changed functionality of the manual auxiliary control console compared with the control console means that the user simply specifically needs to position the rudder angle of the individual rudders at the manual auxiliary control console. In particular in the case of an X-type rudder, said rudder is not directly apparent. The manual auxiliary control 30 console and the first motor controller are connected to transmit the actuation commands. The manual auxiliary control console and the second motor controller are connected to transmit the actuation commands. Operating the manual auxiliary control console results in currents immediately being output from the motor controller to the respective motor and

in the rudder angle being altered. The manual auxiliary control console allows manual operator control with only limited operator controllability, but steerability is preserved, which means that at least reliable resurfacing remains possible, even if both rudder control systems fail.

5

The manual auxiliary control console can be combined without or with the second motor controller in this scenario. The manual auxiliary control console bypasses the actuation of the motor controller by way of the first rudder control system and the second rudder control system in the event of a failure. The first motor controller and the second motor controller can then be actuated in parallel, that is to say in the same manner or at the same time. Even though control of the rudders by way of the manual auxiliary control console must be regarded as complex for normal operation, it is still enough to at least cause a submarine to resurface, that is to say in particular to take all the rudders into the position for maximum rise. This provides further redundancy for the emergency situation of both rudder control systems failing simultaneously, which at least allows a submarine to resurface. This provides not only simple redundancy but also multiple redundancy, which allows a degradation of the system, that is to say even a gradual worsening of the operation of the overall system.

20 In a further embodiment of the invention, the first rudder control system is connected to a first ship electrical subsystem and the second rudder control system is connected to a second ship electrical subsystem. The split over two independent ship electrical subsystems also allows failure of one ship electrical subsystem to be mitigated in this way.

25

In a further embodiment of the invention, the first motor controller is connected to a first ship electrical subsystem and the second motor controller is connected to a second ship electrical subsystem. The split over two independent ship electrical subsystems also allows failure of one ship electrical subsystem to be mitigated in this way.

30

In a further embodiment of the invention, the first electric servomotors are connected to a first ship electrical subsystem and the second electric servomotors are connected to a second ship electrical subsystem. The split over two independent ship electrical

subsystems also allows failure of one ship electrical subsystem to be mitigated in this way.

5 A ship electrical subsystem is a part of the electrical supply system within a submarine that can be operated independently if one part of the supply fails. Each ship electrical subsystem thus has current sources and loads and can be electrically isolated from the overall ship electrical system or other ship electrical subsystems. The submarine can have at least two ship electrical subsystems.

10 In a further embodiment of the invention, the rudder installation has a pneumatic auxiliary control console. Each rudder has a pneumatic servomotor. The pneumatic servomotor is operatively connected to the rudder mechanically or can be connected by way of a control action, for example a mechanical coupling or a feed. The pneumatic auxiliary control console is connected to all pneumatic servomotors pneumatically and can produce or
15 interrupt a supply of operating gas, such as for example compressed air. The pneumatic auxiliary control console and the pneumatic servomotor operate completely independently of the actual electric rudder installation and represent maximum redundancy, for example if all electrical systems fail.

20 In a further embodiment of the invention, the pneumatic auxiliary control console has a pneumatic pressure store, for example a compressed gas canister. The pneumatic auxiliary control console is therefore not reliant on an external system for operation. The auxiliary control console can consist of at least one valve, which is arranged in the connection between the compressed gas canister and the pneumatic servomotor in such
25 a way that the compressed gas reaches or does not reach the auxiliary motor. Ideally, there is provision in the auxiliary control console for a dedicated actuation system for each auxiliary motor, in order to be able to use said actuation system to actuate exclusively failed rudders.

30 In a further embodiment of the invention, the pneumatic auxiliary control console and the pneumatic servomotor are merely designed to put the rudder into a resurfacing position. The pneumatic system is thus used only to allow the fastest and most controlled rise possible, but does not have to be designed to allow more complex control movements,

on the other hand. A further advantage is that a pneumatic pressure store can end up being very small, since only a single rudder movement needs to be able to be performed.

5 There can in particular be provision to use the pneumatic servomotor in addition to the aforementioned embodiments with multiple rudder control installations, multiple motor actuation systems, multiple motors or the manual auxiliary control console, in order to provide further redundancy and therefore to obtain even greater reliability.

10 In a further aspect, the invention relates to a submarine having a rudder installation according to the invention. Especially in the case of submarines, the functionality is needed even in the event of a failure, in order to at least be able to return to the water's surface. At the same time, however, the use of an electric rudder installation is particularly advantageous for reasons of space and weight.

15 In a further embodiment of the invention, there is provision for a submarine having an X-type rudder and a rudder installation according to the invention.

20 In a further aspect, the invention relates to a method for operating an electric rudder installation, in particular a rudder installation according to the invention as described hereinabove. The control console is used to input control commands during normal operation; the control console transmits the control commands to the first rudder control system. The first rudder control system processes the control commands to produce actuation commands. The first rudder control system transmits the actuation commands to the first motor controller. The first motor controller actuates the first servomotors to
25 position the rudders.

If the first rudder control system fails, the second rudder control system takes on the task of the first rudder control system. Redundancy is therefore provided for this level of the electric rudder installation. The scope of functions is completely preserved.

30

In a further embodiment of the invention, the second rudder control system monitors the first rudder control system during normal operation. The second rudder control system takes on the task of the first rudder control system if the first rudder control system fails.

In this scenario, monitoring can consist in parallel execution of the same processes. In this case, the first rudder control system and the second rudder control system ought normally to arrive at identical actuation commands. If the result of the comparison is that the two are identical, then the two rudder control systems are operating normally. If there is a variance, then one is faulty and the other needs to take over. This allows not only a total failure but also a malfunction to be easily identified.

In a further embodiment of the invention, it is possible to change over to the second rudder control system manually if the first rudder control system fails. This has the advantage that during normal operation the second rudder control system is only on standby and therefore less energy is consumed.

The aforementioned further exemplary embodiments of the rudder installation, for example with regard to a second rudder control system, apply here analogously.

In a further embodiment of the invention, the manual auxiliary control console is used to input actuation commands if the first rudder control system and the second rudder control system and/or the control console fail. The disadvantage is that now the actuation commands for the individual rudders need to be input directly, that is to say the operator needs to define the rudder angle himself or herself. In particular in the case of an X-type rudder, this is more complex and less convenient. The functionality of the rudder installation continues to be assured, however, even if multiple systems fail. The manual auxiliary control console transmits the actuation commands to the first motor controller. As such, maneuvering, for example at least resurfacing, is reliably possible.

In a further embodiment of the invention, actuation commands are input using the pneumatic auxiliary control console if the first rudder control system, the second rudder control system and/or the control console and also the manual auxiliary control console and/or the first motor controller and/or the first servomotors fail. Each rudder can therefore be moved by way of a pneumatic servomotor. The pneumatic auxiliary control console actuates all pneumatic servomotors pneumatically. This is even more complex for the operator, since it is thus not possible to predefine a target value for the pneumatic servomotor, but rather the latter is effectively switched on and off in order to attain a

rudder angle. An example in this regard would be total failure of the electrical system, which would have all the aforementioned systems of the electric rudder installation fail at the same time. Therefore only rudimentary maneuvers are now possible; resurfacing is therefore still possible, however.

5

The rudder installation according to the invention is explained in more detail below on the basis of an exemplary embodiment that is shown in the drawing.

Fig. 1 Schematic representation of the rudder installation

10

Fig. 1 schematically shows a rudder installation 10 according to the invention. To simplify matters, only one rudder 20 is shown. A control console 40 is used to input control commands during normal operation and to transfer said control commands to the first rudder control system 51 and the second rudder control system 52. There, the control
15 commands are converted into specific rudder angles, and actuation commands are produced from the rudder angles to be attained. The first rudder control system 51 transmits actuation commands to the first motor controller 61 and the second rudder control system 52 transmits actuation commands to the second motor controller 62. The
20 first motor controller 61 then actuates the first servomotor 31 and the second motor controller 62 then actuates the second servomotor 32. A coupling connects the first servomotor 31 and the second servomotor 23 to the rudder 20 by means of the force transmission system, for example a spindle.

If the control console 40, the first rudder control system 51 and/or the second rudder
25 control system 52 fails, the operator can input actuation commands directly using the manual auxiliary control console 80 and can transmit said commands to the first motor controller 61 and the second motor controller 62. The disadvantage is that the operator now actuates the individual rudders 20 directly and himself or herself needs to predefine the angles of the rudders 20 as appropriate. However, this is adequate for simple
30 maneuvers, in particular for rapid resurfacing.

There is provision for an additional pneumatic servomotor 92 for if the entire electrical system fails. The pneumatic servomotor 92 can be controlled directly pneumatically using

the pneumatic auxiliary control console 90 by completely bypassing electrical systems. Here too, operator controllability is limited, but adequate for a resurfacing maneuver

Reference signs

5	10	rudder installation
	20	rudder
	22	force transmission system
	24	coupling
	31	first servomotor
10	32	second servomotor
	40	control console
	51	first rudder control system
	52	second rudder control system
	61	first motor controller
15	62	second motor controller
	70	housing
	72	housing
	74	housing
	80	manual auxiliary control console
20	90	pneumatic auxiliary control console
	92	pneumatic servomotor

Patent Claims

1. An electric rudder installation (10), the rudder installation (10) having at least three rudders (20), each rudder (20) having at least one first electric servomotor (31), the rudder installation (10) having at least one control console (40), a first rudder control system (51) and a first motor controller (61), the control console (40) being designed to input control commands, the control console (40) and the first rudder control system (51) being connected to transmit the control commands, the first rudder control system (51) being designed to process the control commands and actuation commands, the first rudder control system (51) and the first motor controller (61) being connected to transmit the actuation commands, the first motor controller (61) being connected to the first servomotors (31) to position the rudders (20) in accordance with the actuation commands, **wherein** the rudder installation (10) has at least one second rudder control system (52), the control console (40) and the second rudder control system (52) being connected to transmit the control commands, the second rudder control system (52) being designed to process the control commands and actuation commands, the second rudder control system (52) and the first motor controller (61) being connected to transmit the actuation commands.
2. The rudder installation (10) as claimed in claim 1, **wherein** the rudders (20) have at least one second electric servomotor (32), the rudder installation (10) having a second motor controller (62), the first rudder control system (51) and/or second rudder control system (52) and the second motor controller (62) being connected to transmit the actuation commands, the second motor controller (62) being connected to the second servomotors (32) to position the rudders (20) in accordance with the actuation commands.
3. The rudder installation (10) as claimed in claim 2, **wherein** the first motor controller (61) and the second motor controller (62) are combined in a housing (74).
4. The rudder installation (10) as claimed in either of claims 2 and 3, **wherein** the first electric servomotor (31) and the second electric servomotor (32) each provide only 50% to 95% of the power for adjusting the respective rudder (20).

5. The rudder installation (10) as claimed in one of the preceding claims, **wherein** the control console (40), the first rudder control system (51) and the second rudder control system (52) are combined in a housing (70).
5
6. The rudder installation (10) as claimed in one of the preceding claims, **wherein** the rudder installation (10) has six rudders (20).
7. The rudder installation (10) as claimed in one of the preceding claims, **wherein** the first rudder control system (51) is designed to monitor the second rudder control system (52) and the second rudder control system (52) is designed to monitor the first rudder control system (51).
10
8. The rudder installation (10) as claimed in one of the preceding claims, **wherein** the rudder installation (10) has a manual auxiliary control console (80), the manual auxiliary control console (80) being designed to input actuation commands, the manual auxiliary control console (80) and the first motor controller (51) being connected to transmit the actuation commands, the manual auxiliary control console (80) and the second motor controller (62) being connected to transmit the actuation commands.
15
20
9. The rudder installation (10) as claimed in one of the preceding claims, **wherein** the first rudder control system (51) is connected to a first ship electrical subsystem, the second rudder control system (52) being connected to a second ship electrical subsystem.
25
10. The rudder installation (10) as claimed in one of the preceding claims, **wherein** the first motor controller (61) is connected to a first ship electrical subsystem, the second motor controller (62) being connected to a second ship electrical subsystem.
30
11. The rudder installation (10) as claimed in one of the preceding claims, **wherein** the first electric servomotors (31) are connected to a first ship electrical subsystem, the second electric servomotors (32) being connected to a second ship electrical subsystem.
35

12. The rudder installation (10) as claimed in one of the preceding claims, **wherein** the rudder installation (10) has a pneumatic auxiliary control console (90), each rudder (20) having a pneumatic servomotor (92), the pneumatic auxiliary control console (90) being connected to all pneumatic servomotors (92) pneumatically.
13. The rudder installation (10) as claimed in one of the preceding claims, **wherein** the first rudder control system (51) and the second rudder control system (52) are manually selectable.
14. A submarine having a rudder installation (10) as claimed in one of the preceding claims.
15. A method for operating an electric rudder installation (10), the control console (40) being used to input control commands during normal operation, the control console (40) transmitting the control commands to the first rudder control system (51), the first rudder control system (51) processing the control commands to produce actuation commands, the first rudder control system (51) transmitting the actuation commands to the first motor controller (61), the first motor controller (61) actuating the first servomotors (31) to position the rudders (20), the second rudder control system (52) taking on the task of the first rudder control system (51) if the first rudder control system (51) fails.
16. The method as claimed in claim 15, **wherein** the second rudder control system (52) monitors the first rudder control system (51) during normal operation and takes on the task of the first rudder control system (51) if the first rudder control system (51) fails.
17. The method as claimed in claim 15, **wherein** it is possible to change over to the second rudder control system (52) manually if the first rudder control system (51) fails.
18. The method as claimed in one of claims 15 to 17, **wherein** the manual auxiliary control console (80) is used to input actuation commands if the first rudder control system (51) and the second rudder control system (52) and/or the control console

(40) fail, the manual auxiliary control console (80) transmitting the actuation commands to the first motor controller (61).

- 5 19. The method as claimed in claim 18, **wherein** actuation commands are input using
the pneumatic auxiliary control console (90) if the first rudder control system (51),
the second rudder control system (52) and/or the control console (40) and also the
manual auxiliary control console (80) and/or the first motor controller (61) and/or
the first servomotors (31) fail, each rudder (20) being able to be moved by way of
a pneumatic servomotor (92), the pneumatic auxiliary control console (90)
10 actuating all pneumatic servomotors (92) pneumatically.