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(54) **SYSTEM AND METHOD FOR FAIL-SAFE PROVISION OF AN ANALOG OUTPUT VALUE**

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(57) **ABSTRACT**

A method for fail-safe provision of an analog output value for a control process designed for functional safety, wherein the output value is specified by a control unit as a digital output value and, in a first step, the digital output value is converted into the analog output value via a converter, in a second step, the analog output value is converted into a fail-safe digital output value using fail-safe criteria via a read-back device and, in a third step, the originally provided digital output value is compared with the converted fail-safe digital output value, where in the event of the comparison revealing a deviation or of a plausibility criterion being infringed, a safety action is performed, otherwise, the analog output value is output to the control process with the aid of a release device.

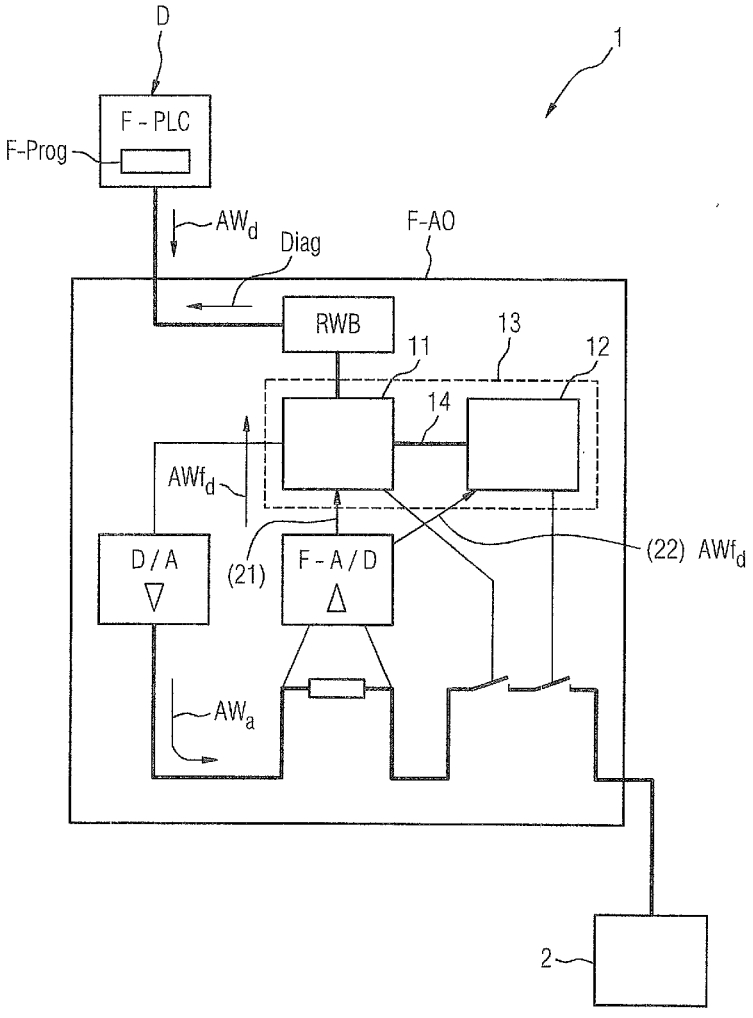


FIG 1

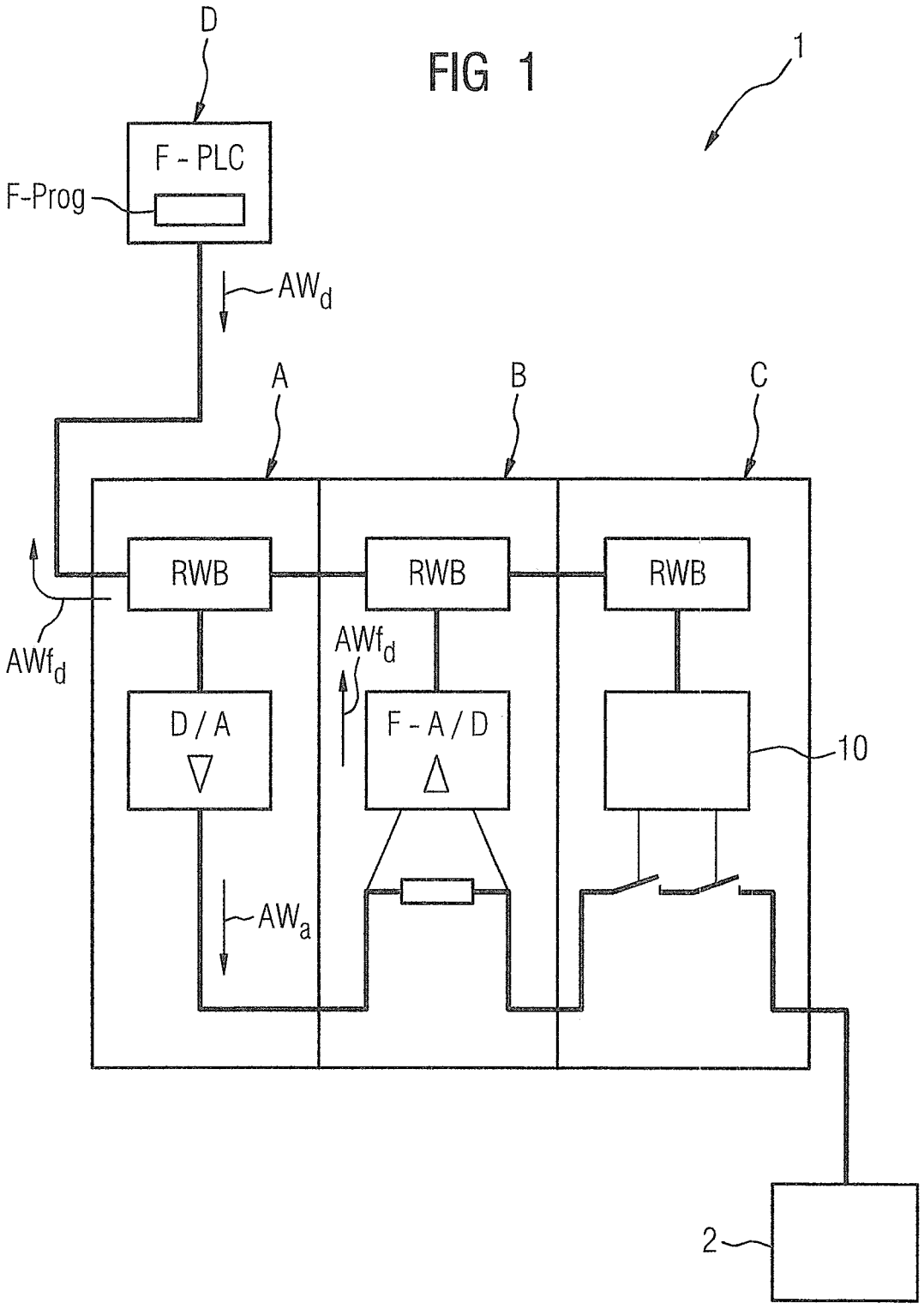
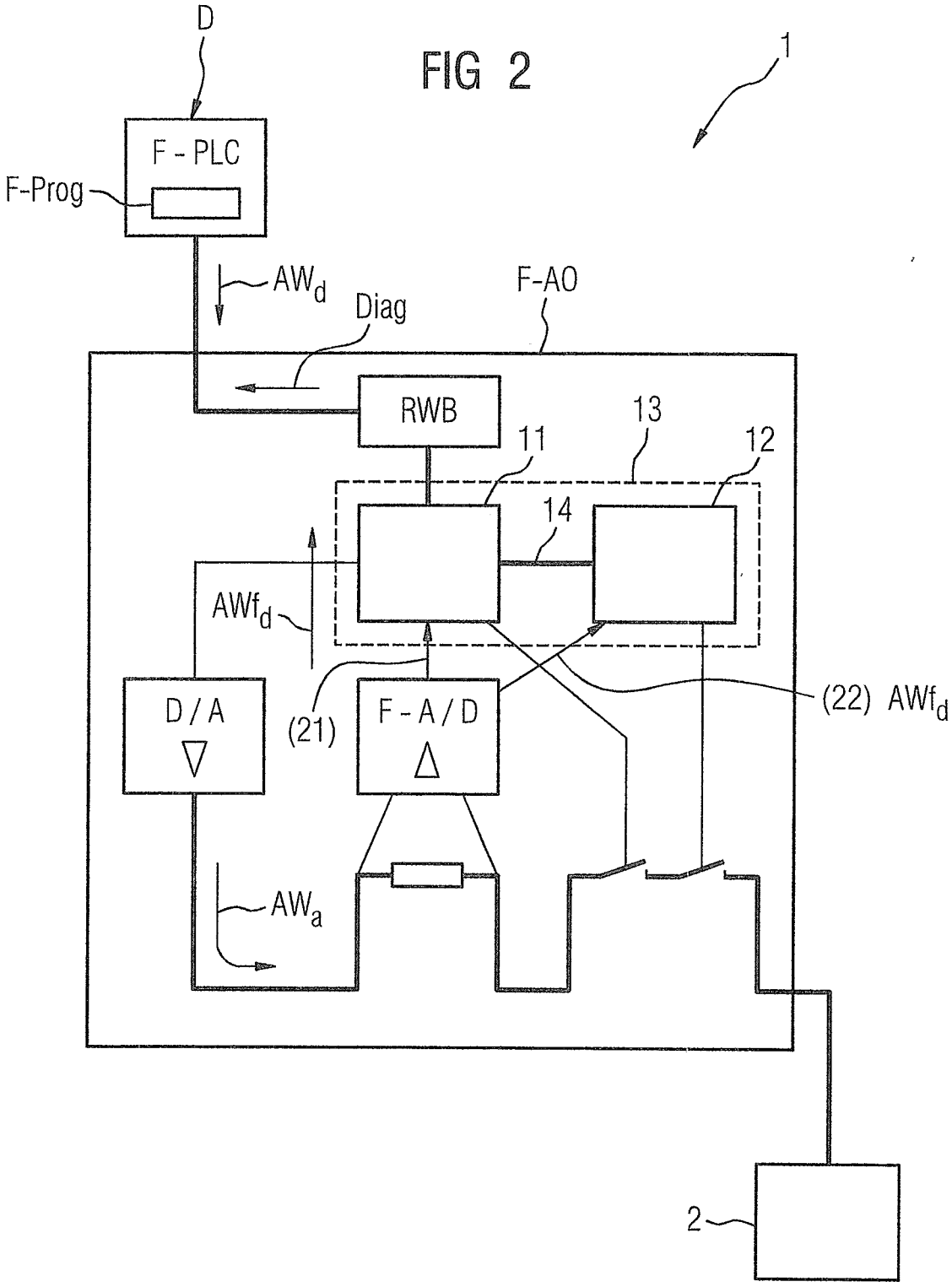


FIG 2


D
1
F - PLC
F-Prog
AWd
Diag
F-AO
RWB
11
13
12
14
AWfd
D / A
(21)
F - A / D
(22) AWfd
AWa
2

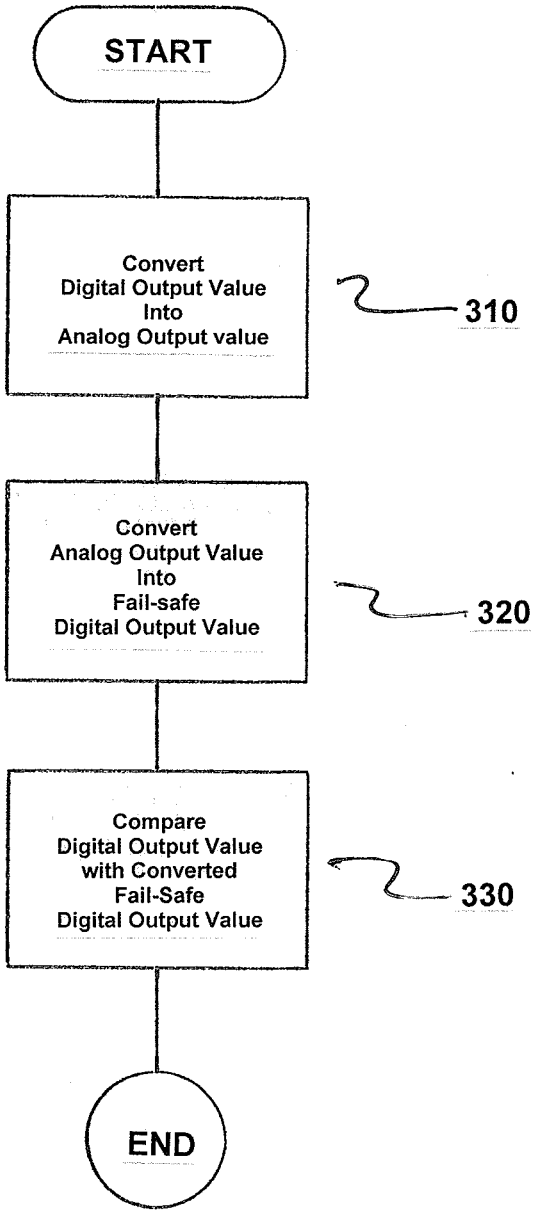

START
Convert Digital Output Value Into Analog Output value
310
Convert Analog Output Value Into Fail-safe Digital Output Value
320
Compare Digital Output Value with Converted Fail-Safe Digital Output Value
330
END

FIG 3

SYSTEM AND METHOD FOR FAIL-SAFE PROVISION OF AN ANALOG OUTPUT VALUE

BACKGROUND OF THE INVENTION

1. Field of the Invention

[0001] The invention relates to a system and method for fail-safe provision of an analog output value for a control process designed for functional safety, where the output value is specified as a digital output value by a control unit.

2. Description of the Related Art

[0002] Recent years have seen an exponential growth increase in the field of application of safety-related control systems (failsafe, functional safety) in automation, in particular industrial factory and process automation.

[0003] An essential requirement for a safety-related control system is the definition of a safe state, which as a rule, is an OFF state or the provision of fail-safe values. The OFF state or the provision of safe substitute values guarantee that a machine stops or assumes a state in which there is no danger to life and limb of the operator.

[0004] Currently, safety-related process control is achieved with fail-safe programmable logic control systems (F-PLC), where the acquisition of the required signals or triggering of the relevant actuators occurs via digital input/output assemblies. With digital output assemblies, only the two states OFF or ON are possible.

[0005] Nevertheless, automation still frequently also makes use of analog regulation processes. Once again fail-safe analog input assemblies are known for this purpose with which analog signals from sensors can be detected in a fail-safe manner. Nowadays, however, the response to these detected analog values also occurs digitally, i.e., in the form of digital output; this does not provide fail-safe analog value regulation.

SUMMARY OF THE INVENTION

[0006] In view of the foregoing, it is therefore an object of the invention to provide a fail-safe output module that enables fail-safe analog regulation up to safety integrity level (SIL3) in accordance with International Electrotechnical Commission (IEC) standard 61508, for example, for analog actuators, such as linear valves, control elements or servo motors with 0 to 20 mA, 4 to 20 mA, 0 to 10 V, +/−10 V or comparable interfaces.

[0007] This and other objects and advantages are achieved in accordance with the invention by a method for fail-safe provision of an analog output value for a control process designed for functional safety, where the output value is specified by a control unit as a digital output value, which comprises, in a first step, converting the digital output value into the analog output value via a converter. In a second step, the analog output value is converted into a fail-safe output value using fail-safe criteria via a read-back device. In a third step, the originally provided digital output value is compared with the converted fail-safe digital output value, in the event of the comparison revealing a deviation or of a plausibility criterion being infringed, a safety action is performed. Otherwise, the analog output value is output to the control process with the aid of a release device.

[0008] Here, the meaning of fail-safe criteria is that, for example, calculations are performed in two diverse ways or that corresponding assemblies are integrated in a dual-channel design or that two integrated computing processors monitor each other. In addition, use is also made of a safety-related bus protocol such as, for example, PROFI Safe. The IEC 61508 standard describes further fail-safe criteria.

[0009] In a first alternative embodiment, repeat conversion of the analog value into a digital value and then subsequent feedback into the control system makes it possible via a plausibility check or a comparison for an impermissible deviation of the actual value from the nominal value to be determined in the control system and, where in the event of a deviation, it is possible to initiate a safe state.

[0010] In a second alternative embodiment, the fail-safe digital output value is generated by the read-back device via two channels and the fail-safe analog output value generated via the first channel is compared with the originally provided digital output value. In addition, the fail-safe digital output value generated via the second channel is compared with the digital output value generated via the first channel.

[0011] Advantageously, with the method, a programmable logic control system designed for functional safety with a safety program, for example, a Simatic S7F with a safety-related, fault-tolerant program, is used as the control unit. It is considered to be particularly advantageous for an analog output assembly to be used as the converter, an analog input assembly configured for functional safety to be used as the read-back device and a digital output assembly designed for functional safety to be used as the release device.

[0012] Accordingly, in an exemplary discrete structure comprising three assemblies, the analog value to be output could be realized with an analog output assembly as a standard assembly, namely not an assembly designed for functional safety. On the other hand, the analog input assembly required for the feedback is a special assembly configured for functional safety.

[0013] Particularly advantageously, the method is used for the application of a fail-safe analog regulation process. Automation frequently makes use of analog regulation processes. Consequently, fail-safe analog input assemblies are also known for this purpose with which analog signals from sensors can be detected in a fail-safe manner. Nowadays, however, the response to these detected analog values also occurs digitally, i.e., so far, the digital output has not enabled fail-safe analog value regulation.

[0014] It is also an object of the invention to provide a system for fail-safe provision of an analog output value for a control process designed for functional safety. Herein, the system includes a control unit that specifies a digital output value, a converter that converts the digital output value into the analog output value, a read-back device that converts the analog output value into a fail-safe digital output value using fail-safe criteria, a release device that is configured to output the analog output value to the control process if the originally provided digital output value and the converted fail-safe digital output value are in conformity. In the event of a deviation or of a plausibility criterion being infringed, a safety action is performed by the control unit. Otherwise, the analog output value is output to the control process with the aid of the release device. Here, once again, the system can be realized in accordance with a first or second embodiment. In a first embodiment, the control unit is configured to

compare the originally provided digital output value with the converted fail-safe digital output value where, in the event of the comparison revealing a deviation or of a plausibility criterion being infringed, a safety action is performed by the control unit. Otherwise, the control unit causes the analog output value to be output to the control process with the aid of the release device.

[0015] Advantageously, in the first embodiment, discrete assemblies are then constructed in the system. The control unit is then formed as a programmable logic control system configured for functional safety with a safety program. The converter is configured as an analog output assembly (standard) and the read-back device is formed as an analog input assembly configured for functional safety and the release device is formed as a digital output assembly configured for functional safety.

[0016] As an alternative to the presently contemplated embodiment, the system can also be constructed from an integrated assembly embodiment. Accordingly, there would then only be a fail-safe analog output assembly, which interacts with the control unit, where a read-back device comprising a first channel and a second channel is arranged in a fail-safe analog output module. Furthermore, a dual-channel testing device is provided, which is configured to compare a fail-safe digital output value provided via the first channel with the originally provided digital output value and in addition to compare a fail-safe digital output value provided via the second channel with the fail-safe digital output value of the first channel.

BRIEF DESCRIPTION OF THE DRAWINGS

[0017] The drawing shows two different exemplary embodiments of the invention, in which:

[0018] FIG. **1** is schematic illustration of a system for fail-safe provision of an analog output value in a discrete structure of three different assemblies in accordance with the invention;

[0019] FIG. **2** is schematic illustration of an alternative embodiment of the system for the fail-safe provision of an analog output value in an integrated configuration, where the functionalities are realized in a fail-safe analog output assembly; and

[0020] FIG. **3** is a flowchart of the method in accordance with the invention.

DETAILED DESCRIPTION OF THE EXEMPLARY EMBODIMENTS

[0021] FIG. **1** depicts a system **1** for the fail-safe provision of an analog output value AW_a for a control process designed for functional safety. The analog output value AW_a is ultimately to be applied to an actuator **2** with an analog interface. In accordance with the invention, the digital output value AW_d provided by a control unit D is converted with an analog output assembly A into an analog output value AW_a, where this converted analog output value AW_a is read back with a fail-safe analog input assembly B and converted into a fail-safe digital output value AWf_d. The analog output assembly A and the fail-safe analog input assembly B are connected via a backplane bus RWB. The control unit D can also communicate with the assemblies A,B via the backplane bus RWB.

[0022] The fail-safe digital output value AWf_d generated by the fail-safe analog input assembly B is provided to the control unit D, which compares the originally provided digital output value AW_d with the converted fail-safe digital output value AWf_d. In the event of the comparison revealing a deviation or of a plausibility criterion being infringed, a safety action is performed. Otherwise, the analog output value AW_a is output to the control process with the aid of a release device arranged in a fail-safe digital output assembly C. Accordingly, the release device or the fail-safe digital output assembly C is configured to forward the analog output value AW_a to the control process when instructed by the control unit D, for example, by a switch via a triggering device **10**.

[0023] For digital-to-analog conversion, the analog output assembly A comprises a digital-analog converter D/A including an amplifier and level adaptation. For reconversion from an analog value into a digital value, the fail-safe analog input assembly B comprises a fail-safe analog-digital converter F-A/D including level adaptation. In the fail-safe digital output assembly C, which can, on the one hand, be configured as a fail-safe digital output or as a fail-safe relay output, the release device is formed as a(logic) triggering device **10**, which comprises or can trigger two series-connected switches to forward the analog output value AW_a.

[0024] FIG. **2** depicts an alternative embodiment of the systems **1** for fail-safe provision of an analog output value AW_a. The functions explained in FIG. **1** for the converter, the read-back device and the release device were structured discretely in FIG. **1** and in FIG. **2** are now realized in a fail-safe analog output assembly F-AO.

[0025] The control unit D again provides a digital output value AW_d, which is guided by the control unit D via a backplane bus RWB in the fail-safe analog output module F-AO. The fail-safe analog output module F-AO now comprises a first triggering device **11** and a second triggering device **12** as release device. The first and second triggering devices **11**,**12** are embedded in a dual-channel tester **13**. The fail-safe analog-digital converter F-AD provides a fail-safe digital output value AFfd via a first channel **21** and via a second channel **22** in each case.

[0026] The dual-channel tester is configured to compare a fail-safe digital output value AWf_d provided via the first channel **21** with the originally provided digital output value AW_d and, in addition, to compare a fail-safe digital output value AWf_d provided via the second channel **22** with the fail-safe digital output value AWf_d of the first channel **21**.

[0027] If a valid analog output value AW_a is present, the first triggering device **11** can close a switch to forward the analog output value AW_a. After verification of the digital output value AW_d provided digitally via the first channel **21** with the digital output value AW_d provided via the second channel **22**, the second triggering device **12** can close the second switch to output the analog output value AW_a and, hence, the analog output value AW_a can be sent to the actuator with an analog interface. For the verification, the first and the second triggering devices **11**, **12** comprise a comparator connection **14**. If one of the two comparisons fails, not only is the output value AW_a not released, but in addition a diagnostic message Diag is sent to the control system D.

[0028] FIG. **3** is a flowchart of the method for fail-safe provision of an analog output value AW_a for a control process designed for functional safety, where the output value AW is specified by a control unit D as a digital output value W_d. The method comprises converting the digital

output value AW_d into the analog output value AW_a via a converter, as indicated in step **310**.

[0029] Next, the analog output value AW_a is converted into a fail-safe digital output value AWf_d utilizing fail-safe criteria via a read-back device, as indicated in step **320**.

[0030] The originally provided digital output value AW_d is now compared with the converted fail-safe digital output value AWf_d, as indicated in step **330**. In an event of the comparison revealing either a deviation or a plausibility criterion being infringed, a safety action being performed, otherwise, the analog output value AW_a being output to the control process aided by a release device.

[0031] Thus, while there have been shown, described and pointed out fundamental novel features of the invention as applied to a preferred embodiment thereof, it will be understood that various omissions and substitutions and changes in the form and details of the devices illustrated, and in their operation, may be made by those skilled in the art without departing from the spirit of the invention. For example, it is expressly intended that all combinations of those elements and/or method steps which perform substantially the same function in substantially the same way to achieve the same results are within the scope of the invention. Moreover, it should be recognized that structures and/or elements shown and/or described in connection with any disclosed form or embodiment of the invention may be incorporated in any other disclosed or described or suggested form or embodiment as a general matter of design choice. It is the intention, therefore, to be limited only as indicated by the scope of the claims appended hereto.

What is claimed is:

1. A method for fail-safe provision of an analog output value for a control process designed for functional safety, wherein the output value is specified by a control unit as a digital output value, the method comprising:

converting the digital output value into the analog output value via a converter;

converting the analog output value into a fail-safe digital output value utilizing fail-safe criteria via a read-back device;

comparing an originally provided digital output value with the converted fail-safe digital output value, in an event of the comparison revealing one of (i) a deviation and (ii) a plausibility criterion being infringed, a safety action being performed, otherwise, the analog output value being output to the control process aided by a release device.

2. The method as claimed in claim **1**, wherein the fail-safe digital output value is provided to the control unit and compared with the digital output value in the control unit.

3. The method as claimed in claim **1**, wherein the fail-safe digital output value is generated by the read-back device via two channels and the fail-safe digital output value generated via a first channel is compared with the originally provided digital output value, and the fail-safe digital output value generated via a second channel is additionally compared with the fail-safe digital output value of the first channel.

4. The method as claimed in claim **1**, wherein the control unit comprises a programmable logic control system configured for functional safety with a safety program.

5. The method as claimed in claim **2**, wherein the control unit comprises a programmable logic control system configured for functional safety with a safety program.

6. The method as claimed in claim **3**, wherein the control unit comprises a programmable logic control system configured for functional safety with a safety program.

7. The method as claimed in claim **2**, wherein the converter comprises an analog output assembly, the read-back device comprises an analog input assembly configured for functional safety and the released device comprises a digital output assembly designed for functional safety.

8. The method as claimed in claim **1**, wherein the method is implemented to apply a fail-safe analog regulation process.

9. A system for fail-safe provision of an analog output value for a control process designed for functional safety, the system comprising:

a control unit which specifies a digital output value;

a converter which converts the digital output value into the analog output value;

a read-back device which converts the analog output value into a fail-safe digital output value utilizing fail-safe criteria;

a release device which is configured to output the analog output value to the control process if an originally provided digital output value conforms to the converted fail-safe digital output value;

wherein in an the event of one of (i) non-conformity and or of a plausibility criterion being infringed, a safety action is performed by the control unit, otherwise, the analog output value is output to the control process aided by the release device.

10. The system as claimed in claim **9**, wherein the control unit is configured to compare the originally provided digital output value with the converted fail-safe digital output value and, in an event of one of (i) the comparison revealing a deviation and (ii) a plausibility criterion being infringed, a safety action is performed by the control unit, otherwise, the control unit causes output of the analog output value to the control process aided by the release device.

11. The system as claimed in claim **9**, wherein the control unit is configured as a programmable logic control system designed for functional safety with a safety program.

12. The system as claimed in claim **10**, wherein the control unit is configured as a programmable logic control system designed for functional safety with a safety program.

13. The system as claimed in claim **9**, wherein the converter is configured as an analog output assembly, the read-back device is configured as an analog input assembly designed for functional safety and the release device is configured as a digital output assembly which provides functional safety.

14. The system as claimed in claim **9**, further comprising:

a dual-channel tester which is configured to compare a fail-safe digital output value provided via a first channel with the originally provided digital output value and in addition to compare a fail-safe digital output value provided via a second channel with the fail-safe digital output value of the first channel;

wherein the read-back device comprises the first channel and the second channel and is arranged in a fail-safe analog output module.

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