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(54) **Title:** METHOD AND SYSTEM FOR DIVERTING REGENERATED ELECTRICAL POWER

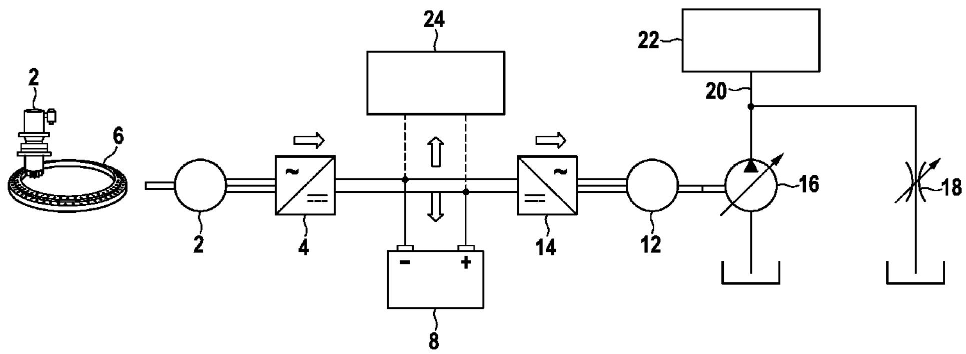

Fig. 1

(57) **Abstract:** A method and a system which are used for diverting electrical power regenerated by an electrically driven first subsystem of a working machine (2) having an electrical power supply (8) are disclosed, wherein, when the electrical power supply (8) is incapable of receiving the regenerated electrical power completely, a second subsystem of the working machine (2) is controlled to receive at least part of the regenerated electrical power (120).

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Method and System for Diverting Regenerated Electrical Power

Description

The present invention relates to a method and a system for diverting electrical power or energy regenerated in a first subsystem.

Background

Mobile working machines, such as excavators, reach stackers or pile drilling machines, may include components that are electrically driven by an electric machine. In such working machines it is possible to regenerate energy using the electric machine, such that regenerated electrical power is fed back to an electrical power supply. Examples are: regeneration during stopping or slowing down of a slew drive of an excavator or of a pile drilling machine; regeneration when lowering a boom or arm of an excavator having a hydraulic system that is driven by an electric machine; and regeneration in a mobile working that has an electrically driven travel drive when braking while traveling down-hill.

Summary

According to the invention, a method and a system for diverting electrical power (or energy) regenerated in a first subsystem with the features of the independent claims are proposed. Advantageous embodiments form the subject matter of the dependent claims and of the subsequent description.

In the method for diverting electrical power regenerated by an electrically driven first subsystem, such as an implement, a (rotatory) tool, a slew drive or a drive train, of a working machine (e.g. a mobile working machine) having an electrical power supply, a second subsystem of the working machine is controlled to receive at least part of the regenerated electrical power (or energy), when an electrical power supply of the working machine is incapable of completely receiving the regenerated electrical power (or energy). Accordingly, an overloading of the electrical power supply or charging above the limits of the electrical power supply (e.g. battery) can be avoided and additional measures (e.g. load resistance) for dissipating power/energy from the first subsystem are not necessary.

In other words, a method of operating a working machine comprising an electrically driven first subsystem having an electrical power supply and a second subsystem, comprises controlling the first subsystem to regenerate electrical energy, storing a first part of the regenerated electrical energy in the electrical power supply, and diverting a second part (the at least part above) of the electrical energy to the second subsystem.

In particular, the at least part of the regenerated electrical power that is received by the second subsystem exceeds the actual (current or normal) power requirement of the second subsystem (during reception of the at least part of the regenerated electrical power). The actual (current, normal) power requirement denotes the power requirement of the second subsystem in order to drive components of the second subsystem in accordance with control signals (e.g. based on a user input) for the components. That is, the actual (current, normal) power requirement is the power that is required by the components of the second subsystem in order to perform their normal functional operation. Accordingly, the received regenerated power is higher than the power that is required by the components of the second subsystem in order to perform the normal (current) function of the second subsystem at the time of reception.

Optionally, the second subsystem is a hydraulic subsystem including an electric motor (or electric machine) that drives a hydraulic pump, wherein a pressure and/or a volume flow of hydraulic fluid output by the hydraulic pump is changed. In particular, the pressure and/or the volume flow may be increased with respect to the normal pressure and/or the volume flow that is provided by the hydraulic pump in a (normal) operation of the second subsystem, i.e., when no regenerated electrical power is received by the second subsystem in excess of the actual power requirement of the second subsystem. That is, the received electrical power is converted into hydraulic power. View over time, the change in pressure and/or volume flow may include an increase in pressure and/or volume flow starting from their normal values (to increased/higher values) followed by a decrease in pressure and/or volume flow back to their normal values.

Optionally, the second subsystem includes a retarder valve and/or an unloading valve, in particular connected to a hydraulic supply line and to a tank for hydraulic fluid; wherein the retarder valve and/or unloading valve is controlled to open such that throttle losses occur, in particular such that the throttle losses correspond to power received during reception of the at least part of the regenerated electrical power in excess of the actual power requirement of the second subsystem. Formulated differently, electrical power is transformed into hydraulic power (by the electric motor and the hydraulic pump of the second subsystem) and hydraulic power in excess of the actual power requirement of the second subsystem (e.g. currently needed to drive an implement) is then transformed into heat using the retarder valve (e.g. an adjustable throttle valve). In case of the unloading valve an excess of volume flow may be guided to the tank.

Optionally, in response to detection of at least one predefined first operation (i.e. operational state or specific working process) of the working machine, the retarder valve and/or unloading valve is opened prior to reception of the at least part of the regenerated electrical power by the second subsystem. This is helpful in situations, where the first subsystem has a higher regeneration power than the (hydraulic) second subsystem can accept, in particular in order to avoid undesired actuation of hydraulic components of the second subsystem.

Optionally, the second subsystem includes a hydraulic component that is provided with the hydraulic fluid; wherein in a control of the hydraulic component the change in pressure and/or volume flow of the hydraulic fluid is taken into account, in particular such that a force and/or torque and/or movement caused by the hydraulic component is unchanged (with respect to the force and/or torque and/or movement caused, if the pressure and/or volume flow is not changed). Accordingly, undesired actuation of the hydraulic component may be avoided.

The system for diverting electrical power regenerated by an electrical driven first subsystem of a working machine having an electrical power supply, comprises a second subsystem of the working machine configured to receive at least part of the regenerated electrical power; and a controller configured to perform the method for diverting electrical power regenerated by an electrical driven first subsystem of a working machine according to an embodiment of the invention.

Further advantages and embodiments of the invention will become apparent from the description and the appended figures.

The invention is shown schematically in the figures on the basis of exemplary embodiments and will be described in the following, with reference to the figures.

Short Description of the Figures

Figure 1 shows a system for diverting regenerated electrical power according to an exemplary embodiment.

Figure 2 shows another system for diverting regenerated electrical power according to an exemplary embodiment.

Figure 3 shows yet another system for diverting regenerated electrical power according to an exemplary embodiment.

Figure 4 shows a flow diagram illustrating steps of the method for diverting regenerated electrical power according to an exemplary embodiment.

Detailed Description

Figure 1 shows a system for diverting regenerated electrical power according to an exemplary embodiment. In Figure 1, as well as in Figure 2 and 3, possible flow paths of regenerated power are indicated by arrows. While not shown in the Figures 1 to 3, at least on controller may be included in the system, which controller is configured to perform or implement a method according to the invention by controlling the system or at least parts of the system (particularly the second subsystem).

The system comprises an exemplary first subsystem that is electrically powered (driven). The first subsystem includes an electric machine 2, an inverter 4 (first inverter) and a slew gearing 6. The inverter 4 is electrically connected to a power supply system including a power supply 8 in order to supply the electric machine 4 with electric power. In the shown example the power supply 8 is a battery. Alternatively or additionally, the power supply may also be or include an electric supply network (e.g. power grid).

In the shown embodiment the first subsystem is an electric slew drive of a working machine such as an excavator in which a cab of the excavator is rotated with respect to an undercarriage of the excavator. The rotation of the cab with respect to an undercarriage may be slowed down by utilizing the electric machine 2 to convert kinetic energy into electric energy, which is supplied to the power supply system 8 through the inverter 4. That is, during certain operations of the working machine (in the shown example the deceleration of the slew drive) power/energy may be regenerated (recuperated) by the first subsystem and transferred to the power supply system.

It will be appreciated that instead of driving a slew gearing the electric machine 2 may drive components of another type. For example, the electric machine may drive a hydraulic machine which supplies a hydraulic system, such as a travel drive (having a hydraulic motor) of the working machine or a hydraulically actuated (by hydraulic cylinders) implement of the working machine. In these examples, energy may be regenerated in case the working machine is braking or is travelling down hill or in case an implement or part thereof (e.g. boom of an excavator) is lowered.

Further, the system of Figure 1 comprises an exemplary second subsystem which includes an electric motor 12 (or electric machine), an inverter 14 (second inverter), a hydraulic pump 16 and an adjustable retarder valve 18 (adjustable throttle valve). The inverter 14 is electrically connected to the power supply system and to the electric motor 12 such that the electric motor 12 is supplied with electric power. The electric motor 12 is arranged to drive the hydraulic pump 16 (e.g. coupled with a drive shaft of the pump. The hydraulic pump 16 is a variable displacement pump, for example. The hydraulic pump 16 is arranged to supply hydraulic components 22 (not explicitly shown; e.g. a hydraulic motor and/or hydraulic cylinders) of the second subsystem with pressurized hydraulic fluid over a hydraulic supply line 20 that is connected to an output of the pump. An input of the pump may be connected to a tank.

The adjustable retarder valve 18 is connected to the supply line 20 and the tank and the second subsystem is further configured to control an adjustable flow of hydraulic fluid from the supply line 20 to the tank, wherein in a closed state of the retarder valve 18 no flow to the tank occurs and the flow may be adjusted by gradually opening the retarder valve 18. For example, by adjusting a cross section of an orifice of the retarder valve 18.

Additionally, the system may optionally comprise other (auxiliary) components 24 that are electrically connected to the power supply system in order to be supplied with electric power. For example, the other components 24 may include one or more of a fan, a coolant pump, and the like. Typically, the (average or peak) power requirement of such other components 24 is much lower (e.g. lower than 10 % or 5 %) than (peak) power requirements of the first and second subsystems and/or the peak power regenerated by the first subsystem.

It may occur that a relatively high amount of power is regenerated (in terms of wattage and/or in terms of energy) by the first subsystem. For example, a slew drive of an excavator may situationally regenerate 50 kW for 2 to 3 s (seconds) or a slew drive of a pile drilling machine may situationally regenerate up to 150 kW for 0.1 to 0.2 s. In these examples the regenerated power may exceed the power that is consumed by the second subsystem in normal operation and optionally the other components at the same time. Depending on the type and/or state of the power supply, the power supply may be incapable to receive the regenerated electrical power completely or incapable to receive the regenerated electrical power that exceeds the power required by the second subsystem and/or other (electrical) components at the same time the power is regenerated. For simplicity and ease of description, the first formulation (“incapable to receive the regenerated electrical power completely”) is intended to include the latter case (“incapable to receive the regenerated electrical power that exceeds the power required by the second subsystem and/or other (electrical) components at the same time the power is regenerated”) as well.

In a situation, when the power supply is incapable to receive the regenerated electrical power completely, the second subsystem may be controlled to change (e.g. increase) the pressure and/or volume flow of hydraulic fluid provided by the hydraulic pump. For example, the rotational speed of the electric motor 12 may be changed and/or a swash angle of the variable displacement pump 14 may be adjusted in order to change the pressure and/or volume flow. This may be seen as changing (in particular increasing) the hydraulic power in the (hydraulic) second subsystem, wherein the received power exceeds the actual power requirement of hydraulically driven components of the second subsystem. The retarder valve 18 may be adjusted to (gradually) open such that a throttled flow of hydraulic fluid through the retarder valve 18 occurs. Accordingly, throttle losses occur, i.e. the excess of hydraulic power may be converted into heat (throttle losses).

Depending on the structure of the (hydraulic) second subsystem measures may be taken in order to avoid an undesired actuation or disturbance of the hydraulic components 22 supplied by the pump 16. For example, an undesired actuation or disturbance may be a change with respect to desired values of a force or torque provided by a hydraulic component (hydraulic cylinder or motor) and/or of a in linear or rotational speed of the hydraulic component. The desired values may be provided by a control unit of the second subsystem, e.g. based on a user input.

In some hydraulic systems pressure and volume flow to the hydraulic components is provided independently of the pressure of the hydraulic pump by using pressure compensators. In such systems a pressure increase in supply line 22 does typically not lead to undesired actuation or disturbance of the hydraulic components 22. For example, in a load sensing system, the retarder valve 18 may be opened and a higher pump pressure may be specified over a load sensing line. In turn the displacement of the variable displacement pump 16 will increase such that the electric motor 14 of the pump has to deliver more mechanical power and consumes more electrical power. That is, the retarder valve 18 acts as an additional hydraulic load (i.e. in addition to the hydraulic components 22) in the load sensing system.

Alternatively or additionally, an increase in volume flow may, for example, be diverted to the tank using a retarder valve 18 as shown and/or an unloading valve that is present in the hydraulic second subsystem. Additionally, the control of the hydraulic components 22 may optionally be adjusted to take the increased pressure of the hydraulic fluid into account. E.g. a proportional valve controlling the flow of hydraulic fluid to a hydraulic cylinder may be controlled to open less as compared to an unchanged pressure.

Another (alternative or additional) optional measure is the provision of a by-pass valve between the supply line 20 and a load sensing line of the load sensing system (not shown), in particular, when an increase in displacement of the pump is not sufficient to absorb the received regenerated electric power in the (hydraulic) second subsystem. A pressure drop across the by-pass valve may be used to increase the pump pressure and avoid an opening of a pressure relieve valve of the load sensing line.

Similar measures for increasing the pressure of hydraulic fluid supplied by the hydraulic pump (pump pressure) may be implemented in an electronic load sensing control.

In other, more simple hydraulic systems (e.g. without load sensing) an increase in pump pressure may lead to undesired actuation or disturbance of the hydraulic components 22. In this case the pressure of the hydraulic fluid should only be increased relatively slowly or avoided as far as possible and the hydraulic power in the second subsystem should mainly be increased by an increase in volume flow.

As noted above, the increase in volume flow may be diverted to the tank using a retarder valve 18 as shown and/or an unloading valve that is present in the hydraulic second subsystem. Additionally, the control of the hydraulic components 22 may optionally be adjusted to take the increased pressure of the hydraulic fluid into account. E.g. a proportional valve controlling the flow of hydraulic fluid to a hydraulic cylinder may be controlled to open less as compared to an unchanged pressure.

In such systems (e.g. without load sensing) a so-called “E-valve” may be used in order to achieve that the pump pressure corresponds to a target value. The additional power is then compensated for by adjusting the displacement of the pump.

A further additional or alternative measure (in particular for a hydraulic second subsystem having no load sensing) is to control the retarder valve to start opening pre-emptively prior to the reception of the regenerated electrical power through the second subsystem. A corresponding point in time, when such a control is to be started, may be determined based on detection of a certain operation (operational state) of the working machine and/or based on detection of a certain control signal (e.g. user input). For example, in case of a slew drive the retarder valve may be controlled to open when is determined that an element driven by the slew drive is rotating, such that it likely that power is regenerated as soon as the rotation stops or slows down. In this case the opening of the retarder valve may be started in reaction to detection of a control signal to stop or slow down the rotation (which due to latencies may lead to an opening of the retarder valve prior to the time of reception of the regenerated electrical power at the second subsystem). It is also possible to determine an opening degree of the retarder valve for the pre-emptive opening based on the detected operation (or properties thereof) of the working machine. For example, based on the rotational speed of the slew drive or based on a travel speed in case of a hydraulic travel drive. In any case a state of the power supply, e.g. a loading state of a battery, may be taken into account.

Due to latencies in a hydraulic second subsystem, e.g. when adjusting the displacement of a hydraulic pump, it may not be possible to receive short (e.g. 0.1 to 0.2 s) and high peaks (e.g. 150 kW) of regenerated power by converting the received electric power into hydraulic power. In order to deal with such situations, alternative or additional measures may be used, which are described hereinafter with reference to Figures 2 and 3.

In Figures 2 and 3 the structure and function of the first subsystem (electric machine 2, inverter 4, slew gearing 6), the power supply system (power supply 8) and, if present, the other components 24 is essentially the same as in Figure 1. The description thereof will therefore not be repeated. Only difference is that the slew gearing 6 is included in a slew drive (shaker) of a pile drilling machine, for example, which may lead to higher power requirements and/or peaks of regenerated power as compared to a slew drive of an excavator as shown in Figure 1 (which is indicated by the drawn three electric machines, which drive the slew gearing 6).

Figure 2 shows another system for diverting regenerated electrical power according to an exemplary embodiment. In Figure 2 the second subsystem includes an electric motor 12 (or electric machine), an inverter 14 (second inverter), a hydraulic pump 16 and a flywheel mass 26 (e.g. a flywheel) or rotational mass. The inverter 14 is electrically connected to the power supply system and to the electric motor 12 such that the electric motor 12 is supplied with electric power. The electric motor 12 is arranged to drive the hydraulic pump 16, e.g. an output shaft of the electric motor coupled with a drive shaft of the pump. The hydraulic pump 16 is a variable displacement pump for example. The hydraulic pump 16 is arranged to supply hydraulic components 22 (not explicitly shown; e.g. a hydraulic motor and/or hydraulic cylinders) of the second subsystem with pressurized hydraulic fluid over a hydraulic supply line 20 that is connected to an output of the pump. An input of the pump may be connected to a tank.

The flywheel mass 26 is coupled to the drive shaft of the hydraulic pump 16 and/or the output shaft of the electric motor 12. When the power supply is incapable to receive the regenerated electrical power completely and regenerated power is diverted to the second subsystem the flywheel mass 26 may be accelerated (by the additional torque provided by the electric motor 12 when additional power is received) such that the kinetic energy of the flywheel mass 26 is increased and may later (after reception of the regenerated electrical power in the second subsystem) be used to (partially) drive the pump 16 and decelerate the flywheel mass correspondingly. In the example mentioned above (150 kW over 0.1-0.2 s), a suitable moment of inertial of the flywheel mass 26 may be 2 $kg \cdot m/s^2$, for example. Additionally, an increase in volume flow may be throttled towards the tank using a retarder valve and/or an unloading valve (cf. above), as it may only partially possible to compensate an increase in volume flow by adjusting the displacement of the pump 16.

Figure 3 shows yet another system for diverting regenerated electrical power according to an exemplary embodiment. In Figure 3 the second subsystem includes a capacitor 28 for buffering electrical power. For example, the capacitor 28 is a supercapacitor. Terminals of the capacitor 28 are electrically connected to the power supply system. In the connection of the power supply 8 to conductive lines of the power supply system a switch 30 is provided parallel to a diode, such that a flow of electrical current to the power supply (corresponding to a flow of electricity when the power supply is charged) is prevented when the switch 30 is opened and possible when the switch 30 is closed. When the power supply 8 is incapable to receive the regenerated electrical power completely, the switch 30 may be opened, such that regenerated electrical power is diverted to the capacitor 28 and electrical energy is stored in the capacitor 30 temporarily. A capacity of the capacitor 28 (e.g. supercapacitor) may be 30 mF, for example. During loading (switch 30 open) its voltage may be increased from 700 V to 1000 V, for example.

It will be appreciated that the embodiments shown in Figures 1, 2 and 3 may be combined. For example, in the system of Figure 1 the flywheel mass as shown in figure 2 may be additionally provided in the second subsystem. In this example, the second subsystem may be controlled to firstly use received power to accelerate the flywheel mass as far as possible (e.g. as far as possible without disturbing the function of components of the second subsystem that are supplied with hydraulic fluid or as far as technically possible) and to secondly open the retarder valve (or any other valve employed in a similar manner) to allow a throttled flow of hydraulic fluid to the tank such that throttle losses occur. In another example, the system of Figure 1 or of Figure 2 may additionally be provided with a capacitor which can be connected to the electrical supply in a switchable manner as shown in Figure 3. In this example, received regenerated power having a high but short peak value (in term of wattage) may be diverted to the capacitor and received regenerated power having a lower peak value but a relatively high amount of energy (in term of watt-hours) may be diverted to the retarder valve or the flywheel mass. Further, all three embodiments of Figures 1, 2 and 3 may be combined as well.

Figure 4 shows a flow diagram illustrating steps of the method for diverting regenerated electrical power according to an exemplary embodiment. Reference is also made to the description of Figures 1 to 3, which includes an extensive description of at least parts of the following steps, which description is not repeated.

In step 100 electrical power is regenerated (recuperated) by the first subsystem. The regenerated electrical power may be detected and/or calculated (e.g. using measurements and/or a model). Step 100 is not part of the method for diverting regenerated electrical power but shown to completely show the process of regenerating and diverting the regenerated power. If step 100 is included in the method, a regeneration method (recuperation method) for a system as described in the preceding is obtained.

In optional step 110 it is determined whether the power supply is incapable to receive the regenerated electrical power completely. This determination may be made based on one or more of a detection of at least one predefined operation (i.e. operational state or specific working process) of the working machine, a charging level of a battery of the power supply, an amount of regenerated electrical power.

In step 120 (in the case that the power supply is incapable to receive the regenerated electrical power completely) the second subsystem of the working machine is controlled to receive at least part of the regenerated electrical power. Specific examples for this process are described in the preceding with reference to Figures 1 to 3.

In case that the second subsystem includes hydraulic components, in optional step 130 the hydraulic components are controlled such that an increase in pressure and/or volume flow is taken into account during the reception of regenerated power in the second subsystem.

As described above, step 120 and/or step 130 may also include that other than hydraulic power sinks are activated, such as using a capacitor (in particular supercapacitor) to store short power pulses or using the rotational mass by accelerating the electric motor to receive a regenerated power peak.

Claims

1. A method for diverting electrical power regenerated by an electrically driven first subsystem of a working machine (2) having an electrical power supply (8), wherein, when the electrical power supply (8) is incapable of completely receiving the regenerated electrical power, a second subsystem of the working machine is controlled to receive at least a part of the regenerated electrical power (120).

2. The method of claim 1, wherein the at least part of the regenerated electrical power that is received by the second subsystem exceeds the actual power requirement of the second subsystem.

3. The method of any one of the preceding claims, wherein the second subsystem is a hydraulic subsystem including an electric motor (12) that drives a hydraulic pump (16), wherein a pressure and/or a volume flow of hydraulic fluid output by the hydraulic pump (16) is changed.

4. The method of claim 3, wherein the second subsystem includes a retarder valve (18) and/or an unloading valve, in particular connected to a hydraulic supply line (20) and to a tank for hydraulic fluid; wherein the retarder valve (18) and/or unloading valve is controlled to open such that throttle losses occur, in particular such that the throttle losses correspond to power received during reception of the at least part of the regenerated electrical power in excess of the actual power requirement of the second subsystem.

5. The method of claim 3 or 4, wherein in response to detection of at least one predefined first operation of the working machine, the retarder valve (18) and/or unloading valve is opened prior to reception of the at least part of the regenerated electrical power by the second subsystem.

6. The method of any one of claims 3 to 5, wherein the second subsystem includes a hydraulic component (22) that is provided with the hydraulic fluid; wherein in a control of the

hydraulic component the increase in pressure and/or volume flow of the hydraulic fluid is taken into account (130), in particular such that a force and/or torque and/or movement caused by the hydraulic component (22) is unchanged.

7. The method of any one of claims 3 to 6, wherein a flywheel mass (26) is coupled with an output shaft of the electric motor (12) and/or a drive shaft of the hydraulic pump; wherein the flywheel mass (26) is accelerated during reception of the at least part of the regenerated electrical power, in particular such that the power received during reception of the at least part of the regenerated electrical power in excess of the actual power requirement of the second subsystem is transferred to the flywheel mass (26).

8. The method of any one of the preceding claims, wherein a determination (110) that the power supply (8) is incapable of receiving the regenerated electrical power completely is made based on one or more of a detection of at least one predefined second operation of the working machine, a charging level of a battery of the power supply, an amount of regenerated electrical power.

9. The method of any one of the preceding claims, wherein the second subsystem includes a capacitor (28), in particular a supercapacitor; wherein the capacitor is charged during reception of the at least part of the regenerated electrical power.

10. The method of any one of the preceding claims, wherein the at least part of the regenerated electrical power is used in the second subsystem as at least one of hydraulic power, electric power charged in a supercapacitor and kinetic power by accelerating a rotational mass.

11. A system for diverting electrical power regenerated by an electrical driven first subsystem of a working machine having an electrical power supply (8), comprising
a second subsystem of the working machine configured to receive at least part of the regenerated electrical power; and
a controller configured to perform the method of any one of the preceding claims.

12. The system of claim 11, wherein the second subsystem includes an electric motor (12) and a hydraulic pump (16), wherein the electric motor drives the hydraulic pump and the hy-

draulic pump is configured to supply pressurized hydraulic fluid to a hydraulic supply line (20) of the second subsystem; wherein the second subsystem further includes a retarder valve (18) and/or an unloading valve connected between the supply line and a tank for hydraulic fluid.

13. The system of claim 11 or 12, wherein the second subsystem includes an electric motor (12) and a hydraulic pump (16), wherein the electric motor drives the hydraulic pump and the hydraulic pump is configured to supply pressurized hydraulic fluid to a hydraulic supply line (20) of the second subsystem; wherein the second subsystem further includes a flywheel mass (26) coupled to an output shaft of the electric motor and/or coupled to a drive shaft of the hydraulic pump.

14. The system of claim 12 or 13, wherein the second subsystem includes hydraulic components (22) connected to the hydraulic supply line (20).

15. The system of any one of claims 11 to 14, wherein the second subsystem includes a capacitor (28), in particular a supercapacitor.

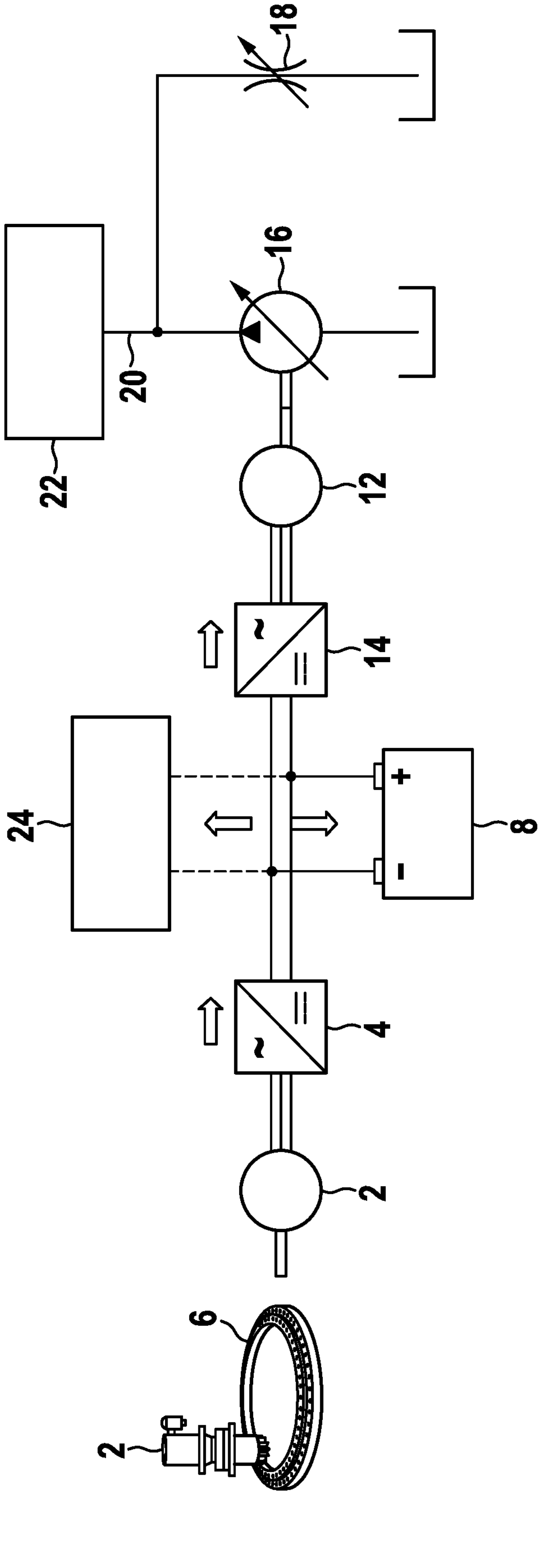

Fig. 1

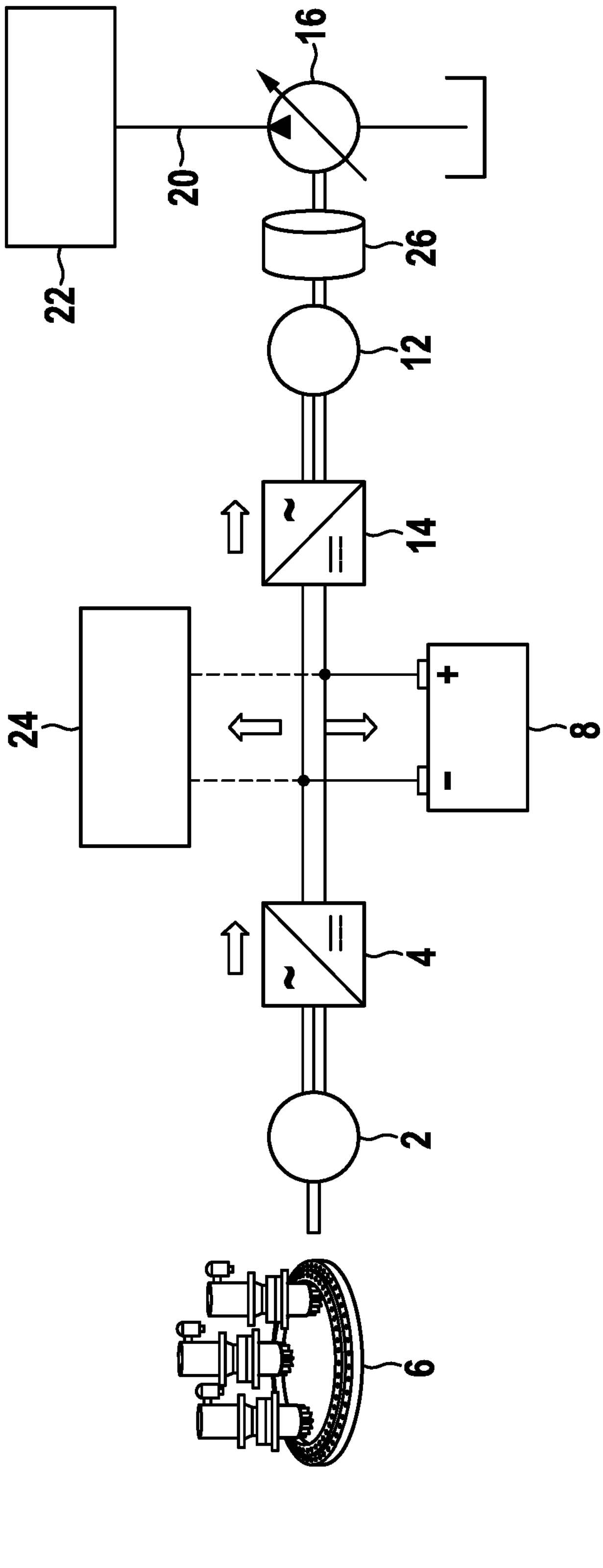

Fig. 2

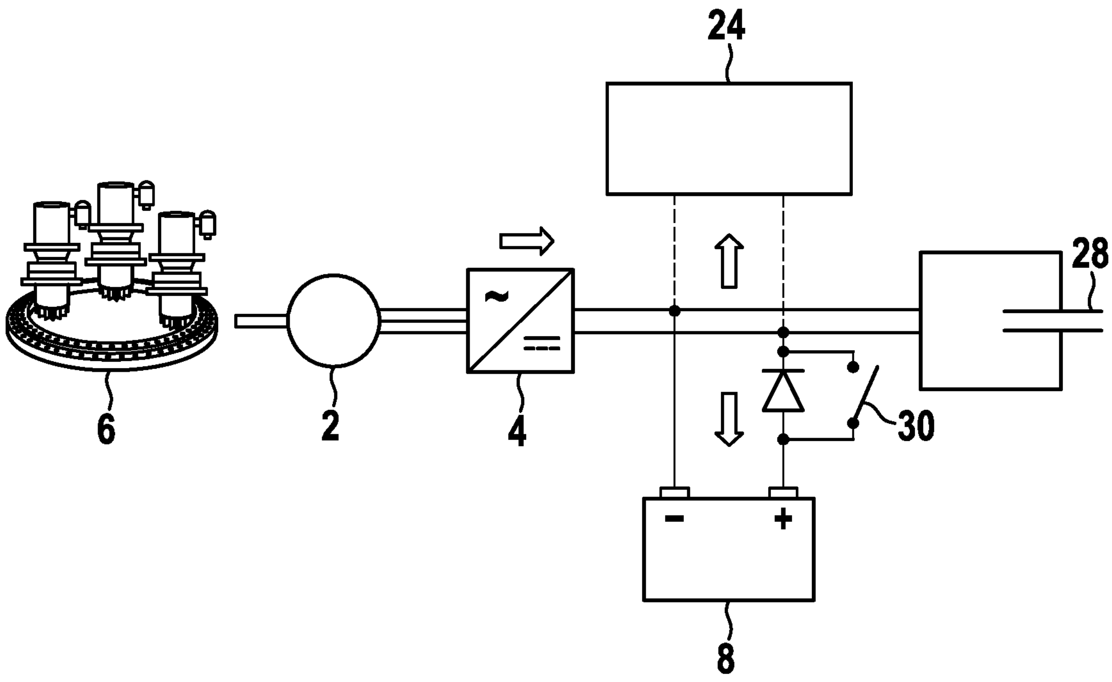

Fig. 3

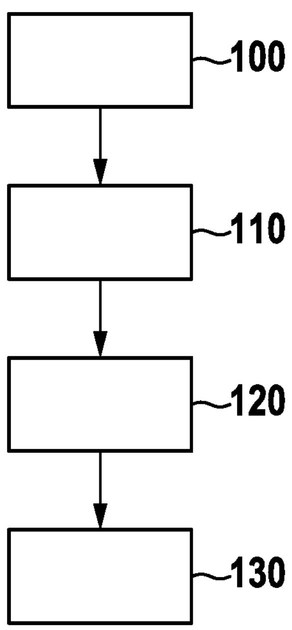

Fig. 4

INTERNATIONAL SEARCH REPORT

International application No.
PCT/CN2022/115494

A. CLASSIFICATION OF SUBJECT MATTER

B60T 13/58(2006.01)i

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

B60T

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

VEN, CNABS, CNTXT, WOTXT, EPTXT, USTXT, CNKI, IEEE: regenerat+, re-generat+, battery, batteries, convert+, dissipat+, used, resistance?, capacity, capacitance, electrical, energy, current

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	CN 102596666 A (COMMISSARIAT ENERGIE ATOMIQUE) 18 July 2012 (2012-07-18) claims 1-17, description, paragraphs [0004], [0037]-[0039]	1, 9, 11, 15
A	US 2014116243 A1 (TENNECO AUTOMOTIVE OPERATING COMPANY INC.) 01 May 2014 (2014-05-01) the whole document	1-15
A	US 2013158827 A1 (CATERPILLAR, INC.) 20 June 2013 (2013-06-20) the whole document	1-15
A	US 6170587 B1 (TRANSPORT ENERGY SYSTEMS PTY LTD) 09 January 2001 (2001-01-09) the whole document	1-15
A	CN 103635636 A (CATERPILLAR, INC.) 12 March 2014 (2014-03-12) the whole document	1-15

☐ Further documents are listed in the continuation of Box C. ☑ See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
16 December 2022	**27 December 2022**

Name and mailing address of the ISA/CN	Authorized officer
National Intellectual Property Administration, PRC **6, Xitucheng Rd., Jimen Bridge, Haidian District, Beijing 100088, China**	**LIU,Fang**
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INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/CN2022/115494

Patent document cited in search report			Publication date (day/month/year)	Patent family member(s)			Publication date (day/month/year)
CN	102596666	A	18 July 2012	WO	2011012610	A1	03 February 2011
				JP	2013500199	A	07 January 2013
				US	2012118683	A1	17 May 2012
				EP	2459420	A1	06 June 2012
				KR	20120038510	A	23 April 2012
				FR	2948331	A1	28 January 2011
				BR	112012001835	A2	16 May 2017
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				JP	2015536861	A	24 December 2015
				CN	104768781	A	08 July 2015
				BR	112015008918	A2	04 July 2017
				KR	20150079668	A	08 July 2015
				DE	112013005150	T5	20 August 2015
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				DE	112012005255	T5	23 October 2014
				WO	2013090082	A1	20 June 2013
				AU	2012352700	A1	12 June 2014
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				WO	9847732	A1	29 October 1998
				EP	0975480	A1	02 February 2000
				NZ	500627	A	26 January 2001
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				WO	2013003014	A1	03 January 2013
				DE	112012002675	T5	03 April 2014