

(19)



(11)

EP 4 538 543 A1

(12)

EUROPEAN PATENT APPLICATION

(43) Date of publication:
16.04.2025 Bulletin 2025/16

(51) International Patent Classification (IPC):
F15B 19/00 ^(2006.01)

(21) Application number: **23203155.9**

(52) Cooperative Patent Classification (CPC):
F15B 19/007; F15B 2211/6336; F15B 2211/71

(22) Date of filing: **12.10.2023**

(84) Designated Contracting States:
**AL AT BE BG CH CY CZ DE DK EE ES FI FR GB
GR HR HU IE IS IT LI LT LU LV MC ME MK MT NL
NO PL PT RO RS SE SI SK SM TR**
Designated Extension States:
BA
Designated Validation States:
KH MA MD TN

(71) Applicant: **Robert Bosch GmbH**
70442 Stuttgart (DE)

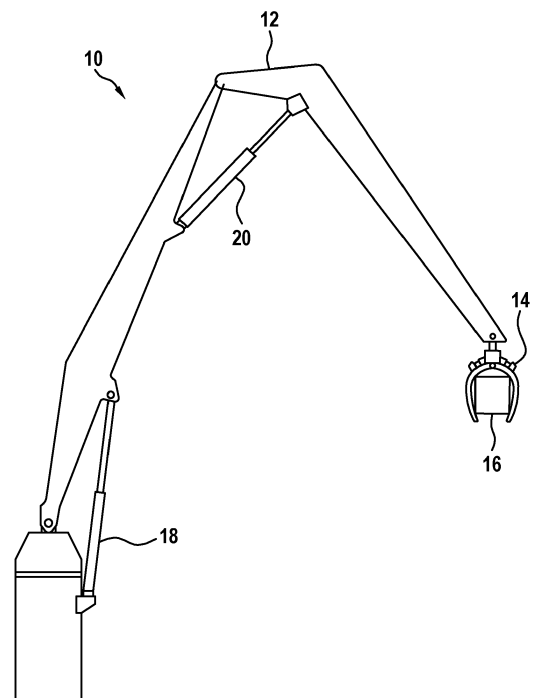
(72) Inventors:
• **SCHMIDT, Lasse**
DK-8800 Viborg (DK)
• **VAN BINSBERGEN-GALÁN, Mikkel**
DK-9000 Aalborg (DK)

(54) **COMPUTER IMPLEMENTED METHOD FOR FINDING AN OPTIMIZED LOAD COLLECTIVE FOR A VARIABLE SPEED DRIVE NETWORK OF A HYDRAULIK MACHINE**

(57) The invention relates to a computer implemented method for finding an optimized load collective for a variable speed drive network of a hydraulic machine comprising multiple cylinder pistons, the optimized load collective being selected from a set of load collectives, the method of selecting the optimized load collective comprising the steps of:

- Obtaining multiple measurement sets (S10) for both speed and force for each piston from a hydraulic machine executing one or several specific task(s) under defined work conditions;
- Obtaining required maximum values for piston's speed, force, and power, either predetermined or on the basis of the measurement sets;
- Extracting a generalized motion pattern (S12) from the measurement sets;
- Creating scaled cycles based on generalized motion pattern using a physical simulation model of the hydraulic machine; and
- Selecting scaling parameters to adhere to and to represent required maximum values.

Fig. 2



EP 4 538 543 A1

Description

[0001] The invention relates to the field of designing hydraulic machines.

[0002] Improving the efficiency of hydraulic systems is of major relevance, viewed in the context of the ongoing climate crisis and electrification trends. In the field of mobile hydraulic systems, the latter is a focus these years, and the transition from internal combustion engines to batteries as main power sources necessitates efficient hydraulics to increase machine up-times and/or reduce battery sizes, and thereby make such solutions feasible both technically and commercially.

[0003] Currently, the two main trends in focus to improve efficiency of hydraulic systems are digital hydraulic technology and electro-hydraulic variable-speed pump/motor technology. The former relies on switching valves that are used in digital displacement, as well as digital flow control units. The switching valves allow for flow control in a highly efficient way compared to conventional proportional valve throttle control, thereby substantially reducing throttle losses. However, the success of digital hydraulic technology is strongly dependent on the properties of the switching valves as well as their control. Several applications with this technology have been considered, illustrating the potential efficiencies achievable with this technology.

[0004] Electro-hydraulic variable-speed pump and motor technology relies on standard component types in terms of fixed or variable hydraulic pumps and motors actuated by electric motors and associated electric drives. These have mainly been considered for hydraulic power units, as well as for actuation of hydraulic cylinders. Regarding the latter, the application of variable-speed pump/motors have been considered in various standalone cylinder drive architectures, and include single electric motors combined with a single pump/motor unit or with tandem pump/motor units. Moreover, drives benefiting from two electric motors with pump/motor units have been considered, allowing for an additional degree of freedom in the drive controls. Furthermore, energy regeneration capabilities have been considered in relation to variable-speed pump/motor technology.

[0005] Several contributions for single cylinder drives based on variable-speed pump/motors have been proposed in both academia and in industry. However, integrated drive systems with this technology have only been considered to a limited extent at this point. Such solutions encompass combinations of variable-speed pump/motor units with directional valves and common pressure rails or common supply pumps. Alternatively, multicylinder drives may be realized by electro-hydraulic variable-speed drive networks (VDNs), for example in "Electro-Hydraulic Variable-Speed Drive Networks-Idea, Perspectives, and Energy Saving Potentials." By Schmidt et al. in *Energies* Vol. 15 No. 3 (2022): p. 1228. Such VDNs are constituted entirely by variable-speed pump/motor units for the nominal operation, with valves only

used for safety measures. Such drive networks allow for power-sharing both electrically and hydraulically, and are realizable with shared cylinder chambers. Besides the inherent efficiency improvement compared to throttle-controlled drives, such drive networks allow for component downsizing, with this dependent on the load cycle(s) of the application.

[0006] The design and dimensioning of a drive system is based on the design requirements for the drive loads. For machines with a simple and constant load, it is easy to define the requirements for the drive system. However, in many applications, such as construction machinery, the workload is complex because the machines are used for different tasks - often tasks for which the machine was not originally designed. In this case, estimates of maximum drive loads can be used to size the drive system. But this is only a suitable approach if each drive in the drive system is connected to a single actuator, since the actuator loads can then be transferred directly to the drive loads. However, this is not the case with networked drive systems, since each drive can be connected to multiple actuators.

[0007] In this case, the loads on the drives are formed by a combination of multiple actuators, so the maximum drive loads may not match the maximum actuator loads. This complicates the drive design considerably, since there is a mapping from the actuator loads to the drive loads that is unique to each drive combination. Therefore, it is necessary to size the drive system based on a load spectrum with one or more load cycles to capture the concurrency of the drive loads. To successfully design a drive network system, the following issues must be thoroughly considered and defined: design requirements, design objectives and control objectives.

[0008] This invention focuses on the definition of the design requirements.

[0009] The problem to be solved by the invention is to provide an easy and reliable method for finding an optimized load collective for a variable speed drive network of a hydraulic machine.

[0010] The task is solved by the objects of the independent claims.

Disclosure of the invention

[0011] According to a first aspect of the invention, the problem is solved by a method for finding an optimized load collective for a variable speed drive network of a hydraulic machine. The optimized load collective is selected from a set of load collectives. The method of selecting the optimized load collective comprises the steps of:

- Obtaining multiple measurement sets for both speed and force for each cylinder piston from a hydraulic machine executing at least one specific task under defined work conditions;
- Obtaining maximum values for piston forces, velo-

cities, and powers;

- Extracting a generalized motion pattern from the measurement sets;
- Determine piston forces by using the generalized motion pattern as input to a physical simulation of the hydraulic machine; and
- Selecting scaling parameters for time, piston stroke, and load related parameters, as to adhere to required maximum values.

[0012] A "variable speed drive network" refers to a complex system used to regulate and control the speed and power of hydraulic drives of a hydraulic machine. The main components of a variable speed drive network in hydraulic machines comprise Variable Speed Drives (VSDs), fixed or variable hydraulic pumps or motors, as well as sensors and feedback systems.

[0013] VSDs are electronic control devices that can variably control the speed and power of hydraulic pumps or motors. They operate in real time and adjust power as needed to save energy and increase efficiency. The sensors and feedback systems are used to monitor various parameters such as pressure, temperature, load, and flow rate. These sensors provide continuous feedback to the VSD network so that it can make power adjustments accordingly.

[0014] The benefits of a variable speed drive network in hydraulic machines are many. They include improved energy efficiency, reduction in number of drives, reduction in installed power, reduced wear and maintenance costs, precise control of processes, and the ability to monitor and control remotely. This is particularly important in applications such as manufacturing, mining or heavy industry, where hydraulic machines are often used to move heavy loads and/or perform precise tasks.

[0015] The design requirements are composed of a load collective, which is a timeseries data array with actuator speeds and forces, including one or more work cycles, together with the required actuator maximum powers, forces, and speeds. If the machine performs a uniform task that repeats itself, the load collective may be composed only of a single cycle. If, however, the machine is used for a multitude of tasks, which is the case for machinery controlled by a human driver, the load collective may be composed of various cycles of one or more typical work tasks. In this case, the actuator loads are complex to specify, for which reason it is more straightforward to take measurements from an existing machine (with whichever drive system is present on that machine) and use these measurements for designing and sizing of a new drive system.

[0016] The design objectives are the choice of parameters for which to rank different drive systems for comparison purposes, and ultimately, what defines what the optimal VDN architecture is for the given load collective. The design objectives may include a single objective or multiple objectives at once, which could be e.g., power consumption, number of components, size, and prize.

The objective values can be calculated and are thus easy to compare between different drive systems.

[0017] The control objectives define the intended conditions under which the actuator loads are fulfilled, and they are defining for which VDNs may be regarded as feasible, considering the degrees of freedom necessary to perform the required tasks.

[0018] Thus, the load collective should reflect the overall work that is being performed. It is the work performed by the actuators that is the end goal, and not the hydraulic output of the drive system itself, as the drive system may be different for the test machine used to take the measurements. Drive induced dynamics and transients should, as such, ideally not be present in the load collective. Furthermore, motion transients caused by disturbances, when the end-effector is engaging with the surroundings, are not meant to be forced by the drive system, i.e., if the end-effector is suddenly stopped by the ground. These effects should not be defining for the maximum accelerations and forces that the drive system should be able to deliver, and consequently, it should not be defining for the design and sizing of the drive system.

[0019] Effects that are induced by a human driver should not be represented in the load collective either so that these effects are not determining for the design and sizing of the drive system. A human driver will adapt to the capabilities of the machines and, if it is an expert, the driver will exploit the full capabilities of the machine to maximize productivity. This is especially important regarding a VDN, since it performs differently than a traditional drive system with a central supply and control valves. A drive system with a central supply can direct a lot (if not all) of its supply flow to a single actuator, but cannot supply several actuators with maximum fluid at the same time. A VDN is inherently different in that it may be able to supply flow for fast simultaneous actuator movements, but may not be able to supply all of its flow to a single actuator. This depends on the VDN architecture.

[0020] When designing and sizing a VDN it is therefore important to consider whether high-speed movement of individual actuators, if present in the load collective, is actually needed, or whether it is a result of the drive system and the driver of the test machine used for acquiring measurement of the load characteristics.

[0021] A VDN system may be designed much more tightly to the specific actuator loads in each quadrant, rather than simply maximum speed and force. By modifying the load collective used for drive sizing, the maximum actuator loads may be preserved while non-essential actuator loads are attenuated, thereby minimizing the working range of the drive systems and hence reducing the size of the drive system.

[0022] This is achieved by analyzing several load cycles within the measurements and from that creating a single representative cycle, the generalized motion pattern, of the overall movements that the machine must perform.

[0023] The reference case for sizing the drives in a VDN is based on raw measurements of several load cycles (LC), each representing a measurement set.

[0024] The maximum values for actuator piston speed, force, and power within these cycles may be considered as the required speeds and forces to be met to maintain the same maximum load capabilities of the actuators, if the maximum values are not predefined on the basis of the machine in question. The maximum values may as such be an input to the process. The maximum speed of a differential cylinder would often be considered in the negative direction and the speed in the positive direction being proportionally lower, equivalent to the area ratio between the rod and piston side. Likewise for the piston force, the maximum force is expected to be in the positive direction while the largest negative force is related to the maximum force by the area ratio. This is logical for a drive system with central supply, since an equivalent amount of flow results in different speeds dependent on the change in volume. However, with VDN systems there is a distributed supply, and hence there need not be any restrictions on the sign of the maximum values, apart from physical restrictions of the components.

[0025] The cycles may be concatenated and each measurement point in the data is analyzed to find the necessary size of hydraulic units and the resultant drive torque.

[0026] The cycles are processed for extracting a generalized motion pattern. If it is evident that neither the speeds nor the forces are adequate to meet the given maximum requirements, scaling is needed. This is done by obtaining the maximum piston speeds and obtaining the maximum piston forces as well as obtaining the maximum piston powers. The maximum power requirement may be chosen not to be a hard requirement to be met if it has no influence on the sizing of drives. However, it should be sought after to maintain loads within the maximum powers, and ideally, it should be maintained.

[0027] When the maximum force and the maximum speed for the pistons are obtained within the load collective, the newly found load collective is considered to be representative of an equivalent workload as compared to the measured cycles and the required maximum values.

[0028] The maximum power can be used as a reference if the power is not used to size the drives making its magnitude insignificant regarding the design requirements. This depends on the applied sizing method and on the hydraulic machine in question.

[0029] With the drive sizing based on the modified load collective, every individual drive in the VDNs may be reduced in size. Consequently, it may be altered what VDNs are considered optimal. Even though the specific choice of VDN topology may not have changed, the sizing results may suggest that smaller drive sizes may be used to supply the necessary loads to the machine, compared to the case where the drive sizes were based on the raw measurements.

[0030] When designing and sizing a drive system for

hydraulic actuators it is important to be mindful of how the machine requirements, design objectives, and control objectives are defined, as these have a significant impact on the sizing of a VDN system. If these factors are properly defined, the drive system may be sized optimally and hence the best possible conditions are given to make the drive system perform to its full potential. Thus, the presented method solves the problem of the invention.

[0031] In an embodiment, only representative measurements set are selected for extracting a generalized motion pattern.

[0032] For example, measurement sets may be discarded because they are notably shorter than other cycles or if they contain larger speed transients for one or more piston than other cycles; such cycles would be outliers to the general work of the machine. Furthermore, if a piston reaches its end-stop, the speed/force dynamic is unrealistic regarding what must be supplied by the drive system, and such measurement cycles may also be discarded.

[0033] In an embodiment, the step of extracting the generalized motion pattern comprises linking each data point of each measurement set to the timely corresponding data point of the other measurement sets and determining the mean motion trajectory.

[0034] By taking a mean cycle, any abrupt speed changes will be flattened, so that, e.g., two individual motions become more overlaid. The goal is to attenuate loads caused by disturbances and unwanted dynamics, while emphasizing the simultaneity between actuator loads.

[0035] In an embodiment, the step of extracting the generalized motion pattern comprises filtering the measurement sets.

[0036] The measurement sets may be filtered. The filtering aims to attenuate unwanted oscillatory dynamics and to be able to obtain continuous speed and acceleration by differentiation of the filtered position signal. The filter may be any low pass type filter of any order and of any frequency appropriate for the application.

[0037] In one embodiment, the maximum force and the maximum speed are obtained separately.

[0038] When scaling for maximum forces, it would be expected that the maximum power would be the limiting factor for the time scaling parameter, however, this is not always the case for a cycle and so the time scaling parameter may be limited by the maximum speed of a piston instead. In this case, the time scaling parameter of each of the two scaling methods are equal, both limited by the maximum piston speed requirement. This may, however, not always be the case and hence the need for separately scaling for maximum actuator speeds and forces.

[0039] In one embodiment, the maximum speed is obtained by extending a stroke of at least one piston until one of the following conditions is fulfilled:

- the maximum speed of said piston is reached;

- the stroke length of said piston cannot be extended further; or
- the maximum piston power is reached.

[0040] In an embodiment, the required piston speed within a load cycle is obtained by scaling of the time vector of the motion by a constant k_{speed} , which may be defined by

$$t_{\text{speed}} = t_{\text{filt}} * k_{\text{speed}},$$

[0041] Wherein t_{speed} is the scaled time, and t_{filt} is the time of the filtered measurement set, so that all piston speeds are within the requirements and at least one piston speed exactly meets its speed requirement. If the piston speeds are all lower than the requirement to begin with, the scaling constant is $k_{\text{speed}} \in (0, 1]$.

[0042] In one embodiment, the forces needed to calculate the pistons power are determined by applying the generalized motion pattern to a simulation model of the machine in question.

[0043] The piston forces needed to calculate the piston powers may be found by feeding the motion pattern to a simulation model of the hydraulic machine with no load mass equivalent to performing the task with no load.

[0044] In one embodiment, the piston forces are determined from applying the generalized motion pattern to the simulation, wherein parameters related to the load are fitted to adhere to the required maximum values.

[0045] Taking basis in the filtered movement pattern based on the measurement sets, a scaling is performed with the aim of reaching maximum piston forces within the load collective. There are several parameters that are fitted for this purpose through an iterative process of tuning the variables and applying it to the simulation model of the hydraulic machine to obtain the actuator forces and powers. Several parameters are fitted; time scaling parameters k_{force} and k_{speed} , relevant masses of payload(s), as well as other load related parameters i.e., friction, external forces, etc. This is done to achieve the required forces with all pistons at some point in the load collective. It would be expected that the maximum power would be the limiting factor for the time scaling parameter, however, if this is not the case then the time scaling parameter is limited by the maximum speed of the piston(s) instead.

[0046] In another aspect, the invention relates to a computer program comprising program code, for executing a method as described above when the computer program is executed on a computer.

[0047] In another aspect, the invention relates to a computer-readable medium containing program code of a computer program to execute a method as described above when the computer program is executed on a computer.

[0048] In another aspect, the invention relates to a system for finding an optimized load collective for a

variable speed drive network of a hydraulic machine, wherein the system is configured to execute a method as described above.

[0049] In another aspect, the invention relates to a hydraulic machine comprising at least n pistons and at least m pumps for operating the pistons and a variable speed drive network, wherein $n \geq 2$ and $m \geq 1$, wherein a load collective is found by a method as described above.

[0050] The described embodiments and further developments can be combined with each other as desired.

[0051] Further possible embodiments, further developments and implementations of the invention also include combinations of features of the invention described above or below with respect to the embodiments that are not explicitly mentioned.

Brief description of the drawings

[0052] The accompanying drawings are intended to provide a further understanding of embodiments of the invention. They illustrate embodiments and, in connection with the description, serve to explain principles and concepts of the invention.

[0053] Other embodiments and many of the advantages mentioned will be apparent with reference to the drawings. The elements shown in the drawings are not necessarily shown to scale with respect to each other.

[0054] The figures show:

Fig. 1 a schematic view of the method according to an embodiment of the invention;

Fig. 2 an exemplary hydraulic machine on which an embodiment of the invention is applied to.

[0055] In the figures of the drawings, identical reference signs denote identical or functionally identical elements, parts, or components, unless otherwise indicated.

[0056] Fig. 1 shows a schematic view of the method according to an embodiment of the invention. In a first step S10 multiple measurement sets for both speed and force for each piston of a hydraulic machine are obtained. The machine may be any hydraulic machine, for example a press, a construction machine like an excavator, a crane, or a production machine. The measurement sets are obtained while the machine is performing a specific task. The machine may be specifically designed for performing said task. But the task may also be a task, which the machine was not specifically designed for. For example, an excavator may be designed for digging at a building site. But it may be used for lifting or pushing heavy objects frequently.

[0057] The task is performed under defined work conditions. The work conditions may include, but are not limited to, a time limit, a power limit, a test mass, a test volume, especially soil or material from a building site, or other environmental parameters.

[0058] Each measurement set contains at least two

timeseries, one for the speed and one for the force of each piston. The speed may especially be derived from the position of the piston during the task. In step S11 maximum values for piston forces, velocities, and powers are obtained.

[0059] In step S12 a generalized motion pattern is extracted from the measurement sets. This step may include some preprocessing, filtering, and selecting of the measurements sets. For example, the measurement sets may be processed for a mean position curve. Each measurement set may be filtered with a certain signal filter. Finally, non-representative measurement sets may be rejected for further processing all along.

[0060] In step S14 a maximum force and a maximum speed for the pistons are determined from the generalized motion pattern of the machine, wherein a physical simulation of the machine is used. For example, the machine being an excavator, the movement of an arm of the excavator can be simulated by applying the equations of motion for each part of the arm to a physical simulation.

[0061] In step S16 scaling parameters for time, piston stroke, and load related parameters are selected, as to adhere to required maximum values.

[0062] Fig. 2 shows an exemplary hydraulic machine, which is represented here as a crane 10. The crane 10 comprises an arm 12 with a gripper 14. The gripper 14 is configured to grab an object 16 having a certain mass. The arm 12 of the crane 10 is divided into three segments, wherein the joints of the segments have a piston for moving the arm 12. Thus, the arm 12 comprises a first piston 18 and a second piston 20. The first piston 18 and the second piston 20 may be pistons with the same or different parameters, e.g., diameter, stroke or stroke length, piston area, working pressure, etc.

[0063] The task of the crane 10 is to move an object 16. The movement may for example, comprise lifting the object 16, rotating and stretching the arm 12 and lowering the object 16.

[0064] The method according to an embodiment of the invention is described with reference to said crane 10.

[0065] For clearance, the measurement sets are recorded from a simulation model of the crane 10 applying a mass load of $m = 5,000$ kg. The drive system implemented for generating these measurements is a single-loop valve-controlled system with a central supply pump.

[0066] At first, a reference trajectory consisting of a series of load cycles is recorded. The different load cycles are supposed to represent the same overall craning task. To realistically represent the imperfect control of the crane 10 by a human driver, the cycles are not identical, and ideally a variety of tasks are represented in the measurements.

[0067] The VDNs that are investigated and sized are the VDNs with so-designated point-to-point topologies, linear topologies, and linear topologies with shared chambers, connected by a short circuit chamber connection (SC). There are 4 possible SC schemes, namely the

connection of chambers $1 \leftrightarrow 3$, $1 \leftrightarrow 4$, $2 \leftrightarrow 3$, or $2 \leftrightarrow 4$. There are 4 VDNs with a point-to-point topology, 48 VDNs with a linear topology, and 36 VDNs with a linear topology and an SC (9 topologies for each SC scheme), giving a total of 88 analyzable VDNs.

[0068] The drives in the drive system are sized based on the required hydraulic displacement as well as the maximum shaft torque of the drive, which makes the drive sizing dependent on the actuator speeds and forces, but not dependent on the actuator power. Each drive in the network is sized based on the needed flow, and a hydraulic displacement unit is fitted to a suitable simulation model. In this example, the relation between the displacement and the nominal flow of said model is not linear, as the smaller hydraulic units can run at a higher speed than the larger units at nominal condition.

[0069] It is assumed that nominal flow of the hydraulic unit can always be achieved, regardless of the pressure level at the ports. One should, in fact, account for the suction pressure of the hydraulic unit, especially for drives which are connected to a low-pressure fluid tank. The size of the hydraulic unit for each drive is then determined as.

$$\max(Q_d) \leq Q_{unit} \rightarrow D_d = D_{unit},$$

based on the maximum flow through it during the load collective ($\max(Q_d)$) and rounding up to the nearest unit that can handle that flow (Q_{unit}) which subsequently determines the displacement of the hydraulic unit ($D_d = D_{unit}$). Here, Q_d is a time series vector with flow values for the drive (d). For example, a required drive flow of 900 L/min would be rounded up to the next available nominal unit flow of 1000 L/min equivalent to a unit of size 500 ccm.

[0070] The drive torques are then found as

$$\tau_d = D_{unit}(p_A - p_B),$$

using the pressure difference across the unit during the load collective, with τ_d being the time series vector with torque values for each drive (d). The design objectives are then calculated as

$$\sum D = \sum_{i=1}^{n_d} D_i, \sum \tau_{max} = \sum_{i=1}^{n_d} \max(|\tau_i|)$$

for the sum of hydraulic displacements and the sum of maximum drive torques, respectively, with n_d being the number of drives in the VDN.

[0071] Next, the drive is sized. For example, the drives in each VDN are based on the raw measurements of five load cycles (LC). Only the cycles LC1, LC3 and LC5 are selected from the measurement data as these three cycles are the most alike and therefore considered to

be the best representation of the overall work of the crane 10. LC2 may be discarded as it is notably shorter than the other cycles and contains larger speed transients on the boom speed compared to the other cycles. LC4 may be discarded as the boom piston reaches end-stop, making the speed/force dynamic unrealistic in regard to what must be supplied by the drive system. The maximum values for actuator piston speed, force, and power within these three cycles are considered as the required speeds and forces to be met to maintain the same maximum load capabilities of the actuators.

[0072] The three cycles LC1, LC3 and LC5 are concatenated and each measurement point in the data is analyzed to find the necessary size of hydraulic units and the resultant drive torque. Then, the cycles are processed.

[0073] The first step is to obtain a mean position trajectory based on the three cycles LC1, LC3 and LC5, to obtain a general motion pattern. Furthermore, the mean load cycle is filtered with a sixth order low pass filter with a filter frequency of 3 Hz, filtering for unwanted oscillatory dynamics and to be able to obtain continuous speed and acceleration. Applying this filtered motion cycle to an inverse mechanical simulation model of the crane 10 (motion as input and forces as output) with a 5,000 kg test mass load. The result may be that neither the speeds nor the forces are adequate to meet the requirements given in the defined work conditions. Thus, the system may be sized.

[0074] To achieve the required piston speed within a load cycle, first the time vector of the motion is scaled by a constant k_{speed} . Through an iterative process, the stroke length is extended either until the required speed is met, the stroke length cannot be extended further, or the maximum piston power is achieved. The piston forces needed to calculate the piston powers are found by feeding the motion pattern to the simulation model of the crane with no load mass equivalent to moving the crane 10 in free air.

[0075] Next, the piston forces are determined for achieving the required maximum values. There are two parameters that are fitted for this purpose through an iterative process of tuning the variables and applying it to the simulation model of the crane 10 to obtain the actuator forces and powers. As with the speed scaling, the time vector is scaled by some constant, k_{force} . The other fitting parameter is the load mass that the crane 10 is carrying. The two fitting parameters are fitted to $k_{\text{force}} = k_{\text{speed}}$ and $m = 3,720$ kg. This is done to achieve the required forces with both pistons.

[0076] The resultant load collective is the concatenation of the two scaled cycles, where the load is scaled aiming for maximum actuator speeds and forces, respectively.

[0077] Even though the specific choice of VDN topology may not have changed, the found load collective suggests that smaller drive sizes may be used to supply the necessary loads to the crane 10.

Claims

1. Computer implemented method for finding an optimized load collective for a variable speed drive network of a hydraulic machine comprising multiple cylinder pistons, the optimized load collective being selected from a set of load collectives, the method of selecting the optimized load collective comprising the steps of:

- Obtaining multiple measurement sets (S10) for both speed and force for each cylinder piston from a hydraulic machine executing at least one specific task under defined work conditions;
- Obtaining maximum values (S11) for piston forces, velocities, and powers;
- Extracting a generalized motion pattern (S12) from the measurement sets;
- Determine piston forces (S14) by using the generalized motion pattern as input to a physical simulation of the hydraulic machine; and
- Selecting scaling parameters (S16) for time, piston stroke, and load related parameters, as to adhere to required maximum values.

2. Computer implemented method according to claim 1, wherein, only representative measurements set, in which significant disturbances are not present, are selected for extracting a generalized motion pattern.

3. Computer implemented method according to one of the previous claims,

wherein the step of extracting the generalized motion pattern comprises linking each data point of each measurement set to the timely corresponding data point of the other measurement sets, and determining the mean piston motion for each data point.

4. Computer implemented method according to one of the previous claims, wherein the step of extracting the generalized motion pattern comprises filtering the measurement sets.

5. Computer implemented method according to one of the previous claims, wherein the maximum force and the maximum speed are obtained separately.

6. Computer implemented method according to one of the previous claims, wherein at least one maximum piston speed is obtained by applying a time scaling factor to a generalized motion pattern.

7. Computer implemented method according to one of the previous claims, wherein at least one maximum piston speed is obtained by extending a stroke of at

least one piston until one of the following conditions is fulfilled:

- the maximum speed of said piston is reached;
- the stroke length of said piston cannot be extended further; or
- the maximum piston power is reached.

8. Computer implemented method according to one of the previous claims, wherein the forces needed to calculate the pistons power are determined by applying the generalized motion pattern to the simulation. 10
9. Computer implemented method according to one of the previous claims, wherein the piston forces are determined from applying the generalized motion pattern to the simulation, wherein at least one load related parameter, in particular a payload and/or an external force is set. 15
20
10. Computer program comprising program code, for executing a method according to one of the previous claims when the computer program is executed on a computer. 25
11. Computer-readable medium containing program code of a computer program to execute a method according to one of the claims 1 to 8 when the computer program is executed on a computer. 30
12. System for finding an optimized load collective for a variable speed drive network of a hydraulic machine, wherein the system is configured to execute a method according to one of the claims 1 to 8. 35
13. Hydraulic machine comprising at least n pistons and at least m pumps for operating the pistons, wherein $n \geq 2$ and $m \geq 1$, wherein a load collective is found by a method according to one of the claims 1 to 8. 40

45

50

55

Fig. 1

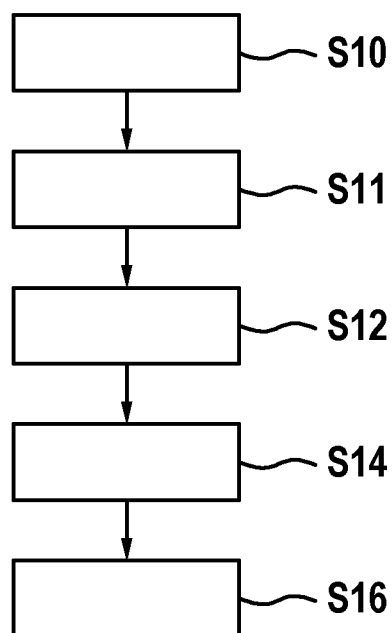
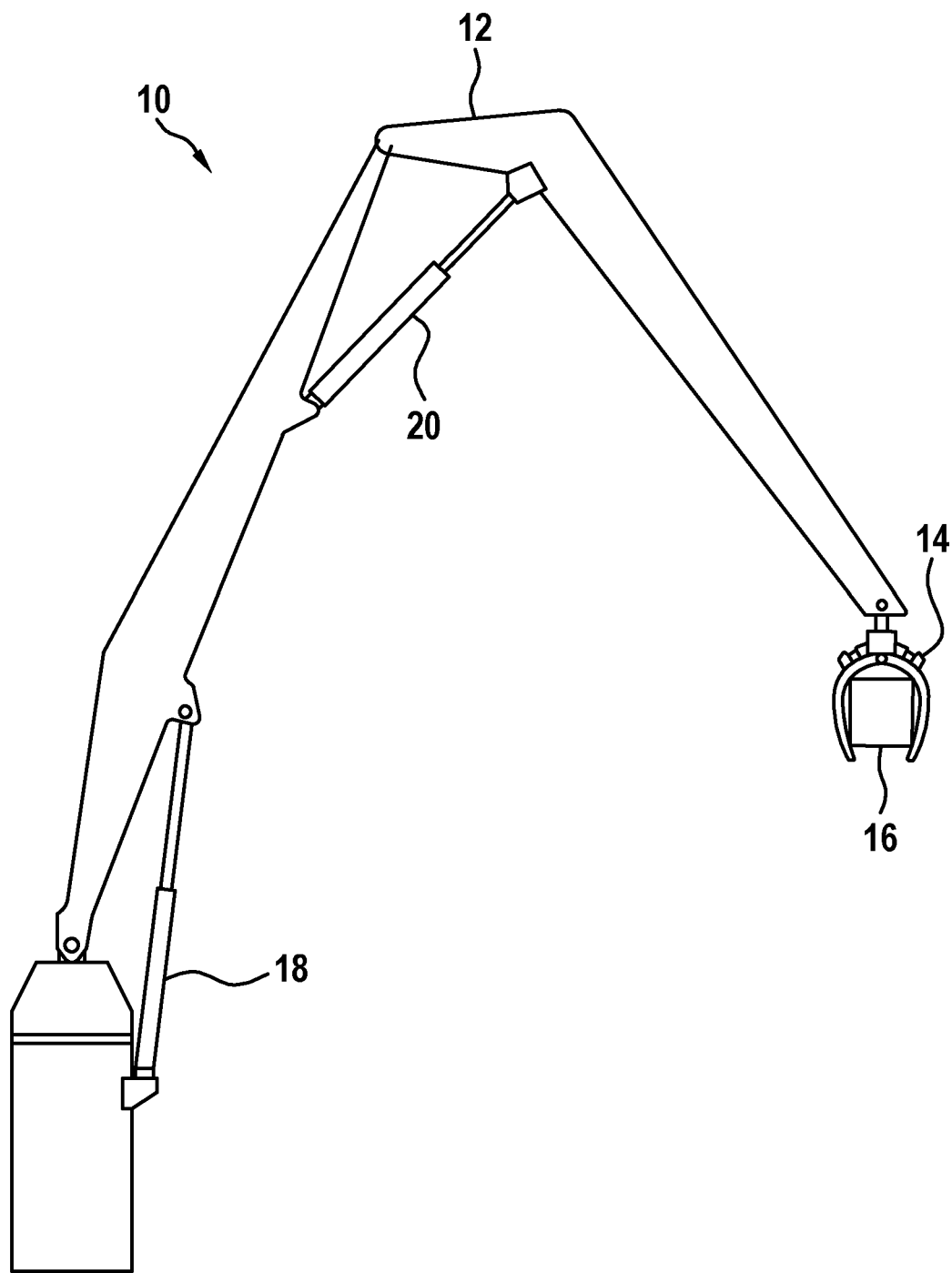


Fig. 2





EUROPEAN SEARCH REPORT

Application Number

EP 23 20 3155

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	DE 10 2008 063927 A1 (BOSCH GMBH ROBERT [DE]) 25 June 2009 (2009-06-25) * paragraph [0037] - paragraph [0047]; figures 3, 4 * * paragraph [0050] *	1, 10-12	INV. F15B19/00
A	DE 10 2011 106356 A1 (DAIMLER AG [DE]) 5 January 2012 (2012-01-05) * paragraphs [0016], [0021] *	1-13	
A	DE 10 2022 105430 A1 (J D NEUHAUS HOLDING GMBH & CO KG [DE]) 14 September 2023 (2023-09-14) * paragraph [0018] *	1-13	
X	POPPY W: "HYDRAULIKBAGGER. ÖSCHRITTMACHER DER BAUMASCHINENENTWICKLUNG", BAUMASCHINENTECHNIK B.M.T, BAUVERLAG GMBH. WIESBADEN, DE, vol. 40, 1 January 1993 (1993-01-01), pages 30, 32-34, XP000411957, ISSN: 0005-6693	13	
A	* page 33, column 3, paragraph 1 *	1-12	TECHNICAL FIELDS SEARCHED (IPC) F15B F04B E02F G06F
The present search report has been drawn up for all claims			
Place of search Munich		Date of completion of the search 27 March 2024	Examiner Díaz Antuña, Elena
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document		T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document	

EPO FORM 1503 03.82 (P04C01)

ANNEX TO THE EUROPEAN SEARCH REPORT
ON EUROPEAN PATENT APPLICATION NO.

EP 23 20 3155

5

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report. The members are as contained in the European Patent Office EDP file on
The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

27-03-2024

10

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
DE 102008063927 A1	25-06-2009	NONE	
DE 102011106356 A1	05-01-2012	NONE	
DE 102022105430 A1	14-09-2023	DE 102022105430 A1 WO 2023169765 A1	14-09-2023 14-09-2023

15

20

25

30

35

40

45

50

55

EPO FORM P0459

For more details about this annex : see Official Journal of the European Patent Office, No. 12/82

REFERENCES CITED IN THE DESCRIPTION

This list of references cited by the applicant is for the reader's convenience only. It does not form part of the European patent document. Even though great care has been taken in compiling the references, errors or omissions cannot be excluded and the EPO disclaims all liability in this regard.

Non-patent literature cited in the description

- **SCHMIDT et al.** Electro-Hydraulic Variable-Speed Drive Networks-Idea, Perspectives, and Energy Saving Potentials. *Energies*, 2022, vol. 15 (3), 1228
[0005]