

Description

[0001] The invention relates to an arrangement for generating a series of periodic fluid pressure pulses. The invention further relates to a use of such a hydraulic arrangement. Further, the invention relates to a method of performing a test cycle for hydraulic components.

[0002] Hydraulic circuits are widespread in the present technology for a vast variety of purposes. Consequently, not only a large variety of arrangements exist, but also a large variety of different hydraulic components.

[0003] To be able to provide sufficiently reliable hydraulic machines with a sufficiently long lifetime, the hydraulic components of such hydraulic machine designs need to be tested. One frequently employed test is a repetitive pressurisation and depressurisation of hydraulic components, where the characteristics of the respective component are detected and/or analysed at the end of the test, potentially meeting criteria which define a 'pass' after a characteristic period of testing.

[0004] Over time, stringent reliability requirements have lead to the development of industry standard test cycles, and an accordingly high number of pressurisation cycles have to be applied to a hydraulic component to be tested. This can take a significant amount of time. Therefore, to speed up the testing process, and consequently to be able to shorten the development and certification time of hydraulic components, it is desired to perform a large number of pressurisation cycles in a short period of time (and to create a corresponding test device for testing hydraulic components to provide this). Hence, the time between two pressurisation cycles should be sufficiently low (where a minimum length of time is nevertheless necessary according to typical test cycle standards), or - seen vice versa - the frequency of the pressurisation cycles should be accordingly high.

[0005] Furthermore, depending on the hydraulic component to be tested, the pressures that have to be generated by the test device have to be quite large at times. For example, for a variety of hydraulic devices, a test pressure of some 300, 400 or 500 bar is frequently called for. Considering the number of pressure cycles to be performed, typical cycle lengths are in the hundreds, thousands or even higher. Furthermore, the test device should also be energy efficient, since the energy consumption of such hydraulic test devices can be quite significant.

[0006] In view of the various requirements for hydraulic test devices, a large number of designs of hydraulic test devices has been proposed in the state of the art.

[0007] However, there is still room for improvement. In particular, there is a desire to further increase the frequency of the applied pressure pulses and/or to lower the energy consumption of the hydraulic test device.

[0008] It is therefore the object of the present proposal to suggest a hydraulic arrangement for generating a series of periodic fluid pressure pulses that is improved over such hydraulic arrangements for generating a series of

periodic fluid pressure pulses that are known in the state-of-the-art.

[0009] It is another object of the invention to propose a method of performing a test cycle for hydraulic components that is improved over methods of performing a test cycle for hydraulic components that are known in the state-of-the-art.

[0010] The present invention solves these objects.

[0011] It is suggested to design a hydraulic arrangement for generating a series of periodic fluid pressure pulses in a way that it comprises a synthetically commutated hydraulic pump, a fluid output connector for an external device, a fluid conduit connecting said synthetically commutated hydraulic pump and said fluid output connector, a triggerable orifice device arrangement connected to said fluid conduit, at least a pressure transducer being fluidly connected to said fluid conduit, and a control device for controlling said hydraulic arrangement. In principle, the hydraulic arrangement for generating a series of periodic fluid pressure pulses can be connected to any kind of external (hydraulic) device. The decisive feature is mainly that the respective external device has to be applied with a series of periodic fluid pressure pulses that may be delivered by the presently proposed hydraulic arrangement. Further, the external device can be a more or less complex hydraulic arrangement, or may be simply a single hydraulic component. A particular use for applying a series of periodic fluid pressure pulses to an external device is, however, a test device/test stand for testing the reliability and sufficient quality over a certain time span of an external device to be connected to the presently proposed hydraulic arrangement. However, different uses are possible as well. When talking about a series of periodic fluid pressure pulses, typically a comparatively large number of consecutive fluid pressure pulses have to be envisaged. In particular more than 10, 100, 1000, 2000, 5000 or even 10,000 fluid pressure pulses have to be applied for a usual test run for the external device to be tested. Furthermore, when talking about a series of periodic fluid pressure pulses, the frequency of the fluid pressure pulses/the distance between two consecutive periodic fluid pressure pulses should normally be about the same. However, certain deviations from an identical spacing between two consecutive fluid pressure pulses may be present as well. As an example, the distance between two consecutive fluid pressure pulses should usually not differ by a factor of more than 1.1, 1.2, 1.5, 2, 3 or 5. This may also apply to the smallest and largest temporal distance between two consecutive fluid pressure pulses in a series/block of 10, 100, 500 or 1000 fluid pressure pulses. Furthermore, usually the individual fluid pressure pulses of the series of periodic fluid pressure pulses should be essentially the same. This may apply to the height of the fluid pressure pulses (maximum pressure), the length of the fluid pressure pulses (in particular the time length during which the peak pressure is applied; plateau phase) and/or the shape of the fluid pressure pulses. In particular, this may apply to two consecutive

fluid pressure pulses, or to fluid pressure pulses out of a series of up to 10, 100, 500 or 1000 fluid pressure pulses that do differ from each other with respect to one or several of the aforementioned features. The difference should be usually not larger than 1.1, 1.2, 1.5, 2, 3 or 5. While the fractional difference is usually obvious to a person skilled in the art, when it comes to the pulses' heights or the pressure pulses' length/width, the shape may be defined in a numerical way by the slope of the rising flank, the slope of the falling flank and/or the length of the plateau phase (where the aforementioned fractions may be applied in analogy).

[0012] The hydraulic pump is of a synthetically commutated hydraulic pump type. These pumps are also known in the state of the art as so-called Digital Displacement® Pumps (DDPs). They form a unique type of hydraulic pumps with electrically actuated fluid inlet valves for the pumping chamber(s). Sometimes they also show actuated fluid outlet valves for the pumping chamber(s), in particular, if a motoring mode for the pump has to be achieved, in which the machine works as a hydraulic motor. The at least one pumping chamber of the synthetically commutated hydraulic pump shows a chamber with cyclically variable inner volume. Typically, a reciprocally moving piston is arranged in the chamber for creating such an internal volume with cyclically varying volume. When the inner volume expands, fluid is sucked into the chamber through an inlet conduit, past the open inlet valve. Contrary to standard pumps, the inlet valve remains open, unless an electric signal is applied to the inlet valve. If the inlet valve remains open during the complete cycle (no closing actuation of the inlet valve), the fluid in the pumping chamber is simply pushed back into the inlet conduit, so that no effective pumping of fluid towards the high-pressure side is effectuated. If, however, the fluid inlet valve is closed by actuating the valve at an appropriate time, the fluid cannot flow back into the fluid inlet conduit, but will be pushed through the fluid outlet valve into the fluid outlet conduit at an appropriately high pressure. It is to be noted that - in principle - the fluid inlet valve can be electrically closed at any position during the contraction phase of the inner volume in the course of a pumping cycle. Consequently, a fraction between 0% to 100% of the overall available pumping displacement may be pumped towards the high-pressure side (i.e. into the fluid outlet conduit). It is to be noted that due to the design of synthetically commutated hydraulic pumps, the pumped volume (reference to verb pump mean pumping towards the high-pressure side of the synthetically commutated hydraulic pump; this is in contrast to an "idle pumping" back towards the fluid inlet channel past the open fluid inlet valve) of fluid can be varied on a cycle-by-cycle basis between every possible fractional value, i.e. a jump from 0 to 50% or 100% (just to name some examples) from one pumping cycle to the next pumping cycle (or vice versa) is possible. While the synthetically commutated hydraulic pump may be designed with a single pumping chamber, usually the synthetically

commutated hydraulic pump comprises several individual pumping chambers with an actuated fluid inlet valve and a (possibly actuated) fluid outlet valve, respectively. It is to be noted that the pumping fractions of the various pumping chambers can be individually chosen and may be different from each other, albeit they can be the same as well. The fluid output connector (high-pressure side) of the hydraulic arrangement can be designed according to any connector type that is known in the prior art. In particular, they can be simply an end tube with a thread, but they can also be of a fast connector type or the like.

[0013] The pressure transducer can be of any design that is known in the state of the art. In particular, the pressure transducer can be a traditional pressure transducer or potentially a pressure gauge.

[0014] The triggerable orifice device arrangement may be a device that opens abruptly, i.e. in a very short time span, from a (essentially) closed position to its open position (or vice versa from an open to its closed position). The nature of the triggering signal may vary. It might be an externally applied signal, where the signal might be applied in form of an electric signal, a fluid pressure signal, a mechanical signal, a magnetic signal, or the like. Further, it may be an internal signal as well, meaning that the triggering orifice device arrangement may be triggered based on the fluid pressure that is present at one of its fluid ports, or possibly based on a pressure differential across the triggerable orifice device arrangement. Similarly, the closing behaviour of the triggerable orifice device arrangement may be based on an externally applied signal and/or an internal pressure value (pressure value at one of the fluid ports and/or pressure difference). Similarly, both may be true as well, meaning, for example, that the triggerable orifice device arrangement may be triggered by an external signal, but opens at a certain internal pressure as well, whatever comes first. When talking about a short opening time, typically opening times of less than 1 ms, 2 ms, 5 ms, 7.5 ms or 10 ms from the closed to the triggered, open position (and/or vice versa) may be envisaged. It should be noted that the triggering signal and/or the triggering times might vary depending on the applied triggering signal and/or on whether the triggerable orifice device arrangement opens or closes. While according to a typical design, the orifice of the triggerable orifice arrangement device has a comparatively large fluid flow cross-section, so that a large fluid flow throughput may be realised, it is also possible that the orifice is somewhat restricted, so that a certain throttling behaviour is present (which might be useful for an inclined depressurisation flank of a pressure pulse. According to a possible example, the size of the orifice of the triggerable orifice device arrangement may be changeable and/or variable as well, for example by a mechanical replacement of an orifice and/or based on an externally applied adjustment signal (the signal may be applied mechanically (possibly even by an operator), electrically, fluidly or the like). Only for completeness it should be mentioned that it is also possible that the trig-

gerable orifice device arrangement does not show an express fast opening and/or fast closing behaviour. Rather, it is also possible that the triggerable orifice device arrangement is designed as a variable orifice device, for example. Hence, the notion "triggerable orifice device arrangement" might also be replaced by "orifice device", in particular "variable orifice device".

[0015] The control device may be of an arbitrary design. Typically, the control device is an electronic device, more preferably a programmable electronic device, like an electronic controller or the like. It is to be noted that the control device may be a dedicated device for the hydraulic arrangement for generating a series of periodic fluid pressure pulses, but may be also a so-to-say universal device that does not only control the hydraulic arrangement for generating a series of periodic fluid pressure pulses, but also does control other devices and/or performs at least one measurement functionality. An example for this would be a measurement of some property of the external device, once such an external device is connected to the fluid output connector of the hydraulic arrangement. In particular, the control device may control the functionality of the synthetically commutated hydraulic pump, in particular of the actuation of its controllable valves. This way, the control device can particularly control the rising pressure flank of the series of periodic fluid pressure pulses, and potentially also maintains a certain pressure for a certain time (plateau phase), in particular in a fully pressurised state and/or in a fully depressurised state (waiting times with high-pressure or plateau phase/waiting times with low-pressure or dwell phase). Furthermore, the control device may control the functionality of the triggerable orifice device arrangement, in particular it may apply a triggering signal for the triggerable orifice device arrangement. Furthermore, the control device may input data from the at least one pressure transducer, in particular for performing its control functionality. For completeness, it should be mentioned that the control device may also control various other devices and/or may input data from various other devices, in particular of devices that will be explained and suggested in the following. In particular, the control device may also comprise a connection to a user terminal or to a computer network, so that it can be easily programmed and/or so that the data can be easily retrieved from the control device. Further, the communication to the various controlled devices and/or sensors or the like may be made using dedicated electric cables and/or using data buses, where a combination of both systems is also possible, so that some devices are actuated by dedicated lines (usually at least the control signal for the controlled valves), while data buses are used for (some of the) other devices.

[0016] It is suggested to design the hydraulic arrangement for generating a series of periodic fluid pressure pulses in a way that said triggering orifice device arrangement comprises a trigger valve unit that can be triggered using an external signal, wherein said trigger valve unit can be triggered electrically, mechanically and/or fluidly,

and wherein said trigger valve unit is preferably designed as a pilot operated check valve. Such pilot operated check valves are also known as pilot-to-close check valves, at least for certain designs. The triggering can relate to an opening of the trigger valve unit and/or to a closing of the trigger valve unit. Although the trigger valve unit is presently proposed to be a pilot operated check valve, different valves can be used for this purpose as well.

[0017] In particular, a triggerable orifice device arrangement may be designed in a way that it comprises two or more subunits. In particular, one of the subunits - namely the trigger valve unit - may be of a type that it can effectuate a fast opening and/or closing of the trigger valve unit, essentially without any intermediary steps. The trigger valve unit may be so-to-say a "binary" unit that either shows an open or closed state. In particular, at least an opening time and/or a closing time of the trigger valve unit (and hence of the triggerable orifice device arrangement) may be faster than 1 ms, 2 ms, 3 ms, 5 ms, 7.5 ms or 10 ms. Further, what is said in the context of the triggerable orifice device arrangement may be applied to the trigger valve unit as well, at least in analogy. Furthermore, the triggerable orifice device arrangement may comprise an orifice device that can induce a certain (possibly variable) fluid flow cross-section or can provide a certain fluid throughput in a controllable way (where it is to be understood that the fluid flow throughput usually depends on the pressure difference across the orifice as well). It is to be noted that the orifice can be a fixed orifice, an exchangeable orifice (for example by mechanically exchanging the orifice) or a variable orifice, where the variation can be effectuated by mechanical means (either by a mechanical actuator and/or possibly even by an operator) or by another type of external signal, like any external electric and/or fluid signal. The respective subunits may be arranged in series, i.e. one following another along a fluid conduit.

[0018] Furthermore it is proposed to design the hydraulic arrangement in a way that the triggerable orifice device arrangement comprises an orifice with a variable size, wherein the size of the orifice can be preferably controlled by the control device and/or by varying a mechanical orifice. In particular, such devices are as such known as so-called proportional valves. When using a variable orifice, in particular the shape and/or slope of a pressure-decreasing flank of the pressure pulses can be chosen essentially freely.

[0019] Furthermore, it is suggested that the hydraulic arrangement is designed and arranged in a way that the fluid conduit comprises a pressure intensifier device, wherein the pressure intensifier device divides the fluid conduit into a medium-pressure fluid conduit and a high-pressure fluid conduit. Preferably, the pressure intensifier device provides, at least at times, a physical fluid connection between the medium-pressure fluid conduit and the high-pressure fluid conduit. In particular, this physical fluid connection that is provided at least at times

may be realised by at least one check valve that forms part of the pressure intensifier device and/or is arranged in the vicinity (upstream and/or downstream along the fluid conduit) of the pressure intensifier device. However, it is to be noted that such a physical fluid connection may be designed with certain limitations, for example that there is no direct fluid connection (but only a fluid connection via a certain fluid circuitry (including certain devices), via a fluid reservoir, via a charging pump or the like, or that the fluid connection is somehow limited, for example by means of an orifice (in particular with a small fluid flow cross-section), a check valve and/or a switchable valve or the like. Using this design, it is possible to create very high-pressure fluid pulses in the fluid output connector and hence for the external device. Nevertheless, the synthetically commutated fluid pump may be of a simpler design, since it has to create only pressures in a lower (typically medium-pressure) range. Just to name some examples, using a pressure intensifier, the medium-pressure circuit can range between 20, 30, 40, 50, 60, 70, and 80 bar (lower limit) and 30, 40, 50, 60, 70, 80 and 100 bar (upper limit). Nevertheless, the high-pressure fluid conduit can show a pressure in a range that is typically required for high-pressure hydraulic equipment. Namely, the pressures can be in a range between 200, 225, 250, 275 and 300 bar (lower limit) and 300, 400, 500 bar or even higher (upper limit, if there is an upper limit at all). Furthermore, the notion of a medium-pressure fluid conduit and a high-pressure fluid conduit can be a relative notion, meaning that the medium-pressure fluid conduit has a lower pressure (or, at times, about the same pressure), as compared to the high-pressure fluid conduit, at least during certain parts (preferably major parts) of a pressurisation and depressurisation cycle. Further, both the medium-pressure fluid conduit and the high-pressure fluid conduit may have a higher pressure than the pressure before the synthetically commutated hydraulic pump, which may be ambient pressure and/or the pressure of a fluid reservoir, feeding the synthetically commutated hydraulic pump. As a pressure intensifier device, all devices that are known in the prior art can be used for this purpose. Typically, such a pressure intensifier device comprises a slidable piston, the slidable piston comprising a piston section with a larger cross-section and a piston section with a smaller cross-section. The cross sections of the respective piston sections will translate into a corresponding ratio of the input and output pressures. It is to be noted that typically such pressure intensifier devices show the feature that the fluid flow volume that is available on the high-pressure side is typically smaller, quite frequently even significantly smaller, as compared to the fluid flow volumes on the medium-pressure side (lower pressure side) of the pressure intensifier device. However, this is not necessarily a disadvantage. In particular, in the case of using the hydraulic arrangement for purposes of a test device for other hydraulic devices, no large fluid flows are usually needed on the high-pressure side. Rather, the pressures that can

be reached are typically the relevant feature. Only for completeness it should be mentioned that a plurality of (two, three, four or more) pressure intensifier devices can be used as well.

5 **[0020]** Furthermore, it is suggested to design the hydraulic arrangement in a way that it comprises a check valve that is arranged in the fluid conduit. The fluid conduit can be a hose or tube. However, the fluid conduit can also be a void in a certain part of the various parts of the hydraulic arrangement (such as a number of channels in a metal block). In particular, a check valve may be arranged between the medium-pressure fluid conduit and the high-pressure fluid conduit. More preferably, the check valve is designed and arranged to be a part of the pressure intensifier device. In particular, it can be designed to be located inside of the movable piston of the pressure intensifier device (a typical standard design for a pressure intensifier device is assumed). Also, the check valve can be arranged in the housing of the pressure intensifier device. Hence, such a check valve might be addressed as a "pressure section separating check valve" (since it separates the fluid conduit into two sections with a different pressure level), or the like. Additionally or alternatively, in an embodiment without the pressure intensifier an equivalent check valve to the pressure section separating check valve can be arranged between a first part of the fluid conduit and a second part of the fluid conduit. This equivalent valve functions to replace the pairing of the pressure intensifier and the pressure separating check valve. The first part of the fluid conduit neighbours (is directed towards) the synthetically commutated hydraulic pump, while the second part of the fluid conduit neighbours (is directed towards) the fluid output connector. Hence, such check valve may also be referred to as a "functional section separating check valve" (since it separates the fluid conduit into two functional sections), or the like. However, if a pressure intensifier is present, an additional check valve may be present that is arranged between the pressure intensifier device and fluid output connector of a second part of the fluid conduit, and that supplements the check valve (pressure section separating check valve) in the intensifier, will be advantageous. Hence such additional check valve may also be referred to as an isolating check valve. Then, certain parts of the medium-pressure fluid conduit and the first part of the fluid conduit (meaning that the part of the fluid conduit between the synthetically commutated hydraulic pump and the functional section separating check valve or the pressure intensifier, whatever is closer to the synthetically commutated hydraulic pump, will be (a part of) the medium-pressure fluid conduit and (a part of) the first part of the fluid conduit at the same time), as well as parts of the high-pressure fluid conduit and the second part of the fluid conduit will usually fall together (meaning that the part of the fluid conduit between the check valve or the pressure intensifier, whatever is closer to the fluid output connector, and the fluid output connector will be (a part of) the high-pressure fluid conduit and

(a part of) the second part of the fluid conduit at the same time). A (fluid) connection is usually to be interpreted in a way that it may be either directly, or in that at least one other device is arranged in between, typically in series with the check valve. Using a design according to the present suggestion, the hydraulic arrangement is particularly well-suited for a use as a test device for hydraulic components. In particular, by using this arrangement, a suitable supply of a sufficient amount of fluid can be effected at the output connector/for an external device to be connected to the output connector by the synthetically commutated hydraulic pump, albeit a pressure intensifier device, or another type of device, is used. This results in a reliable and affordable design of the hydraulic arrangement. Only for completeness it should be mentioned that even more check valves (three, four, five or more; i.e. a plurality of) can be used as well.

[0021] According to another possible embodiment, the hydraulic arrangement is designed in a way that the triggerable orifice device arrangement, in particular the trigger valve unit, is triggered by fluid pressure in the fluid conduit part between the synthetically commutated hydraulic pump and the check valve. This can be additionally or alternatively understood as a triggering by the fluid pressure in the medium-pressure fluid conduit (in case a medium-pressure fluid conduit is present; this is typically the case if a pressure intensifier device is present) and/or by a triggering by the fluid pressure in the first part of the fluid conduit (in case a first part of the pressure intensifier device is present; this is typically the case if no pressure intensifier device is present). In this context, the fluid pressure may be understood as a fluid pressure ratio between a first pressure in the fluid conduit part between the synthetically commutated hydraulic pump and the check valve (medium-pressure fluid conduit/first part of the fluid conduit) and a second fluid pressure in the high-pressure fluid conduit (second part of the fluid conduit).

[0022] Furthermore, it is suggested that the hydraulic arrangement is designed in a way that it comprises a fluid flux valve that is connected to the fluid conduit, preferably to the fluid conduit part between the synthetically commutated hydraulic pump and the check valve and/or to the medium-pressure fluid conduit and/or the first part of the fluid conduit. Preferably, this fluid flux valve is a needle valve. This way, the fluid pressure in the respective part of the fluid conduit can be easily lowered (decreased), in particular in a way that a (internal) trigger signal for the triggerable orifice device arrangement/the trigger valve unit can be provided. The pressure increase is performed by an appropriate actuation of the synthetically commutated hydraulic pump. It is to be noted that due to the presently proposed fluid flux valve the synthetically commutated hydraulic pump can easily compensate the fluid losses induced by this fluid flux valve. It is admitted that this results in a certain loss of fluid (leakage) and therefore in a certain loss of energy. Preferably the fluid flux valve remains closed during the pres-

surisation period. Following this period, once the target pressure is achieved, the valve opens. Using a needle valve for the fluid flux valve, there is always a leakage, however this leakage and corresponding energy loss is negligible. The generated pump flow will be able to compensate for such leakage losses. Preferably, the needle valve can be adjusted to optimise the hydraulic arrangement for providing a certain frequency, pulse shape or the like of the series of periodic fluid pressure pulses, generated by the presently proposed hydraulic arrangement. Only for completeness it should be mentioned that a plurality of (two, three, four or more) fluid flux valves can be used as well.

[0023] Further, it is suggested that the hydraulic arrangement comprises at least a fluid accumulator that is at least at times fluidly connected to a part of the hydraulic arrangement that is at least at times at an elevated pressure level, wherein said fluid accumulator is preferably connected to a movable device of the hydraulic arrangement to move said movable device to a defined position. The movable device may be particularly (a part of) a pressure intensifier device (for example a slidable piston of a pressure intensifier device). Hence, the fluid accumulator may be connected to a pressure intensifier device. In particular, the fluid accumulator may be connected to said pressure intensifier device to move the pressure intensifier device (or a part thereof) to a standby position. This way, it is easily possible that the synthetically commutated hydraulic pump may create a fluid pressure that may be used to return the pressure intensifier device (or another device) to its standby position or retracted position. It is to be noted that such an active return of the respective device may have to be performed when the fluid pressure in the fluid conduits has to be lowered, and correspondingly the synthetically commutated hydraulic pump will be set to idle mode. Using the presently proposed design, pressurised fluid that is present during a pressurised state of at least parts of the fluid conduits of the hydraulic arrangement can be (temporarily) stored in the fluid accumulator (then, the fluid accumulator may be simply fluidly connected to the respective part of the hydraulic arrangement/the respective fluid conduit), and consequently used for a variety of purposes, in particular for returning the pressure intensifier device to a standby position (fluid accumulator is disconnected from the respective part of the hydraulic arrangement/the respective fluid conduit). Only for completeness it should be mentioned that a plurality of (two, three, four or more) fluid accumulators can be used as well.

[0024] In particular it is possible to design the hydraulic arrangement in a way that the pressure accumulator is fluidly connected to:

the fluid conduit, preferably to the fluid conduit part between the synthetically commutated hydraulic pump and the check valve (functional section separating check valve and/or pressure section separating check valve) and/or to:

the fluid conduit part between the synthetically commu-

tated hydraulic pump and the pressure intensifier device and/or to the medium-pressure fluid conduit and/or to the first part of the fluid conduit. The fluid connection may be effectuated by an accumulator check valve and possibly by a fluid flux limiting valve. This way, a particularly advantageous supply of the fluid accumulator with pressurised fluid can be realised. The pressure achieved in the pressure accumulator is limited by the pressure in the fluid conduit, in particular the first part of the fluid conduit and/or the medium pressure part of the fluid conduit. Furthermore, even if losses occur, they can be minimised by using the presently proposed fluid flux limiting device.

[0025] According to a preferred embodiment of the hydraulic arrangement, the hydraulic arrangement comprises at least one pressure limiting valve. This may be done for safety purposes so that excessive pressures may be avoided. In particular, such pressure limiting valves can be provided in connection with (temporarily) pressurised parts of the presently proposed hydraulic arrangement, in particular by the fluid conduit, the medium-pressure fluid conduit, the high-pressure fluid conduit, the first part of the fluid conduit, the second part of the fluid conduit, the fluid accumulator, or the like.

[0026] Furthermore, it is suggested to design and arrange the hydraulic arrangement in a way to provide a series of periodic fluid pressure pulses with a frequency of above 0 Hz, preferably at least 1 Hz, more preferably at least 3 Hz. Also, other frequencies are possible like at least 0.5 Hz, 2 Hz, 4 Hz or 5 Hz.

[0027] Additionally or alternatively it is suggested to design and arrange the hydraulic arrangement in a way that it may generate an uninterrupted series of at least 10, preferably 20, even more preferred 50 pulses. The uninterrupted series of pressure pulses may also show a length of at least 100, 200, 300, 400, 500, 750 or 1000 pulses.

[0028] Even further, a hydraulic arrangement is suggested that is designed and arranged to provide a pressure at the fluid output connector of at least 350, preferably at least 400, more preferably at least 450, and even more preferably at least 500 bar. In this case, the presently proposed hydraulic arrangement is particularly well suited for the use as a test device. This may be realised with or without a pressure intensifier device, as previously proposed.

[0029] Furthermore, it is suggested to design and arrange the hydraulic arrangement according to the present disclosure as a test device for hydraulic components. Such a hydraulic arrangement can provide the functionality of a test device in a simple, very fast and yet comparatively energy efficient way.

[0030] Furthermore, it is suggested to design the hydraulic arrangement in a way that it comprises an electronic memory that is programmed in a way that the hydraulic arrangement, in particular the control device, performs a method according to the present disclosure (such a method is described in particular in the following in more detail).

[0031] In particular a use of the hydraulic arrangement according to present disclosure as a test device for hydraulic components is suggested.

[0032] Furthermore, a method of generating a series of periodic fluid pressure pulses is suggested, where the hydraulic arrangement according to the present disclosure is used. In particular, the method may be used to perform a test cycle for hydraulic components.

[0033] In particular, the method may be performed in a way that a pressure increase is performed by an appropriate actuation of the synthetically commutated hydraulic pump. The actual actuation of the synthetically commutated hydraulic pump depends on the shape of the fluid pulses to be generated, in particular on the slope and shape of the rising flanks of the pressure pulses. It is to be noted that the actuation may be performed in a way that any pressure losses are compensated, for example the pressure losses due to feeding of a pressure accumulator, due to pressure losses by a fluid flux valve and/or due to a transfer of hydraulic fluid through/past a pressure intensifier device and/or due to fluid consumption of the hydraulic part that is connected to the fluid output port, at least in the initial phase of the pressurisation phase. Once the desired pressure level is reached, the synthetically commutated hydraulic pump may be set to an idle mode (or to a mode with a very small pumping fluid flux to compensate for pressure losses) until a consequent pressure decrease is required. A pressure decrease may be effectuated by simply waiting for the fluid flux valve to vent a sufficiently high amount of fluid, consequently lowering the pressure in the respective part of the hydraulic circuitry to a certain pressure level, at least initially. This lowering of the pressure may be sufficient to trigger the triggerable orifice device arrangement to lower the pressure in the respective part of the hydraulic arrangement, in particular at the output fluid connector, sufficiently fast. The speed of the depressurisation may be varied and/or set to an appropriate slope by choosing orifices of an appropriate size and/or by setting the respective (variable) orifice to an appropriate size. It is to be noted that the size of the orifice may easily be varied during the depressurisation phase, so as to generate an appropriate falling flank (including slope and/or shape of the flank) of the pressure pulses. It is to be noted that possibly the control device may trigger a triggerable orifice device arrangement (opening and/or closing thereof) by applying an appropriate signal to the respective device. In particular, an electric signal may be used for this. The shape of the series of periodic fluid pressure pulses may be improved by monitoring the functionality of the hydraulic arrangement, in particular by monitoring the data sensed by the at least one pressure transducer.

[0034] In particular, it is suggested to perform the method of generating a series of periodic fluid pressure pulses in a way that the series of periodic fluid pressure pulses is preferably primarily controlled by alternately applying a series of a defined number of pumping strokes of the synthetically commutated hydraulic pump, followed by a

series of a defined number of non-pumping strokes of the synthetically commutated hydraulic pump. It is even possible that the generation of a series of periodic fluid pressure pulses is (essentially) solely controlled by alternately applying a series of a defined number of pumping strokes of the synthetically commutated hydraulic pump, followed by a series of a defined number of non-pumping strokes of the synthetically commutated hydraulic pump. The defined number of pumping strokes and/or non-pumping strokes (idle strokes) may be determined in advance by a measurement at the manufacturer. It is possible that the determined number(s) of strokes is (automatically) adapted based on certain considerations (in particular by the controlling device). However, it is also possible that no adaption is used, or only a manual adaption is envisaged. The series of pumping strokes and/or the series of non-pumping strokes may be interrupted by a single one or (very) few non-pumping stroke/pumping strokes, respectively. However, typically it is preferred if the series of pumping strokes and/or the series of non-pumping strokes is not interrupted / is continuous. Using this control scheme in combination with synthetically commutated hydraulic pumps is particularly advantageous, since mechanical energy is essentially only used when building up pressure in the hydraulic arrangement. However, when the pressure is maintained or the pressure is decreased in the hydraulic arrangement, the synthetically commutated hydraulic pump can be (essentially) operated in an idle mode, so that only very little mechanical energy is consumed by the synthetically commutated hydraulic pump. This is of course very energy efficient. Furthermore, since (essentially) only the synthetically commutated hydraulic pump is variably/changeably controlled, the control and the design of the hydraulic arrangement can be particularly simple and possibly wear can be reduced.

[0035] In particular, it is suggested to perform the presently disclosed method in a way that the number of pumping cycles and/or non-pumping cycles differs from each other. Based on the design and functionality of a hydraulic arrangement according to the present disclosure, this may result in a series of pressure pulses, where the high-pressure phases and the low-pressure phases have a similar (or even an (essentially) identical) length in time. This is typically a desired feature for the series of pressure pulses. This way, regulation tests can usually be completed in a very short testing time. Additionally or alternatively, it is suggested to perform the presently disclosed method in a way that the number of pumping cycles and/or non-pumping cycles is adapted using measurement data by the at least one pressure transducer. This way, the series of periodic pressure pulses can be even further optimised. It is to be understood, however, that typically the adaption is only comparatively small (if at all), at least if a reasonable number of pumping cycles and non-pumping cycles is used as a start.

[0036] When talking about fluid in the present context, this might be a liquid, gas, mixture of a gas and a liquid

and even a supercritical fluid where no distinction between gas and liquid can be made anymore. Furthermore, the fluid may contain a certain fraction of solid particles contained therein, although this is usually discouraged. In particular, the fluid can be a hydraulic fluid, for example hydraulic oil, as it is known in the state-of-the-art as such.

[0037] Further advantages, features, and objects of the invention will be apparent from the following detailed description of the invention in conjunction with the associated drawings, wherein the drawings show:

- Fig. 1: a schematic circuitry of a possible first embodiment of a test device for generating a series of periodic fluid pressure pulses according to the present disclosure;
- Fig. 2: a schematic cross section of a pressure intensifier that can be used in combination with the test device according to Fig. 1;
- Fig. 3: a diagram of two consecutive pressure pulses from a series of pressure pulses, showing pressure over time;
- Fig. 4: a diagram of various pressures and fluid flows in the system according to Fig. 1 when creating a pressure pulse;
- Fig. 5: a schematic circuitry of a possible second embodiment of a test device for generating a series of periodic fluid pressure pulses according to the present disclosure;
- Fig. 6: a graph showing a possible fluid output flow over time of a synthetically commutated hydraulic pump, so that a test device according to Fig. 1 or Fig. 5 generates a series of periodic fluid pressure pulse;
- Fig. 7: a flow chart of a possible embodiment of a method of performing a test cycle for hydraulic components.

[0038] Fig. 1 shows a schematic circuitry of a hydraulic arrangement for generating periodic fluid pressure pulses according to the present disclosure according to a first possible embodiment. The hydraulic arrangement is presently designed and intended to be used as a test device 1 for an external device 2, namely a test sample 2 to be tested. The test sample 2 can be any type of hydraulic device that is to be tested by applying a series of periodic fluid pressure pulses. As an example, the test sample might be a fluid valve.

[0039] The test sample 2 is fluidly connected to the test device 1 by means of a fluid output connector 3 of the test device 1.

[0040] The test device 1 comprises a synthetically commutated hydraulic pump 4 that is driven by a mechanical power source, presently an electric motor 5. Synthetically commutated hydraulic pumps 4, also known as Digital Displacement® Pumps (DDPs), are known in the state-of-the-art as such. They are fluid pumps with a unique feature, namely that the fluid output

can be changed between all available pumping fractions from one cycle to the other. The actuation of the synthetically commutated hydraulic pump 4 is presently performed by a digital controller 6. The digital controller 6 is presently connected to various components of the test device 1, and likewise with the synthetically commutated hydraulic pump 4, by means of electric cables 7.

[0041] The synthetically commutated hydraulic pump 4 inputs hydraulic oil from low-pressure line 8 that is fluidly connected to a fluid reservoir 11 that is at ambient pressure. Presently, a suction check valve 12 is arranged at the input side 13 of the synthetically commutated hydraulic pump 4, so that fluid can only flow from the fluid reservoir 11 towards the input side 13 of the synthetically commutated hydraulic pump 4.

[0042] On the output side 14 of the synthetically commutated hydraulic pump 4, the medium-pressure line 9 is arranged. The medium-pressure line 9 directs the fluid towards a pressure intensifier 15, more particularly to the inlet side 16 of the pressure intensifier 15 (see also Fig. 2, where Fig. 2 shows a schematic cross section through a possible embodiment of a pressure intensifier 15 that may be used in a test device 1 according to Fig. 1). Details of the pressure intensifier 15 will be explained further below.

[0043] The pressure in the medium-pressure line 9 is measured by means of a first pressure sensor 18 (pressure transducer), whose measurement data is transmitted to the digital controller 6 for further use.

[0044] Further, a pressure limiting valve 19 is connected to the medium-pressure line 9 for safety reasons. If the medium-pressure line 9 inadvertently exceeds a certain set pressure limit, fluid will be vented towards the fluid reservoir 11 to avoid any damage to the test device 1.

[0045] Furthermore, a needle valve 20 fluidly connects medium-pressure line 9 towards the low-pressure line 8 and consequently towards fluid reservoir 11. The needle valve 20 is presently chosen to be of a type with a variable orifice, where the orifice can be electrically controlled by the digital controller 6. It is to be noted that depending on the shape of the pressure pulses to be generated, a fixed needle valve 20 may be employed as well (or possibly a manual adjustment of the needle valve 20 may be possible as well, so that the test device 1 can easily be adapted from one test setup to another one). Furthermore, the medium-pressure line 9 fluidly connects via a triggering line 21 to the triggering connection of the pilot operated check valve 22 that fluidly connects and disconnects high-pressure line 10 from the low-pressure line 8, as will be described in more detail in the following.

[0046] Another branching line feeds fluid from low-pressure line 8 via an accumulator check valve 25 and a fluid flux limiting valve 26 towards accumulator line 23, and hence into fluid accumulator 24. Again, accumulator line 23 is protected by means of a pressure limiting valve 19 (various pressure limiting valves may be of the same or different designs and/or may show the same or a different opening pressure).

[0047] Pressure intensifier 15 comprises a slidable piston 29 (movable part) in a housing 30. The inlet 16 of the pressure intensifier 15 fluidly connects to an inlet chamber 31 of the pressure intensifier 15, where the slidable piston 29 shows a certain, enlarged cross-section.

[0048] On the other side of the slidable piston 29, at its outlet side 17, the outlet 17 of the pressure intensifier 15 fluidly connects to the outlet chamber 32 with a smaller cross-section of the slidable piston 29, as compared to the cross section of the slidable piston 29, neighbouring the inlet chamber 31.

[0049] If a pressurised fluid is applied to inlet 16 of the pressure intensifier 15, the slidable piston 29 moves to the right side and therefore causes a volume decrease of outlet chamber 32, and thus a pressurisation of the fluid at the outlet port 17 of the pressure intensifier 15. Due to the different cross-sections of the end sides 16, 17 of the slidable piston 29, an input pressure on the inlet side 16 of the pressure intensifier 15 is translated into a potentially significantly higher pressure at the outlet side 17 of the pressure intensifier 15. A typical example is a pressure increase of a maximum pressure of about 50 bar at the inlet side 16 towards an increased pressure at the outlet side 17 of pressure intensifier 15 of about 500 bar.

[0050] The pressure intensifier 15 therefore separates the fluid conduit into two sections with a different pressure level, namely medium-pressure line 9 and high-pressure line 10.

[0051] Although the pressure intensifier 15 constitutes an additional part for the test device 1, therefore introducing additional complexity and additional cost into the test device 1 (in particular since presently also a fluid accumulator line 23 with its respective accompanying components 19, 24, 25, 26 is needed), the use of a pressure intensifier 15 has the advantage that the pressure that has to be delivered by the synthetically commutated fluid pump 4 can be lower. Therefore, a less costly synthetically commutated hydraulic pump 4 can be used and/or the wear of the synthetically commutated hydraulic pump 4 can be reduced due to the lower pressures and/or only a subset of the overall number of pumping cylinders could be used to provide the required flow/pressure, even if the synthetically commutated hydraulic pump 4 would be able to generate the required high pressure levels.

[0052] The outlet side 17 of the pressure intensifier 15 is connected to the high-pressure line 10 that feeds the test sample 2 through the fluid output connector 3. The pressure in the high-pressure line 10 is measured by a second pressure sensor 33, whose measurement data is again transmitted to the digital controller 6.

[0053] To prevent a backflow of fluid from the high-pressure line 10 to the pressure intensifier 15, a fluid outlet check valve 34 is provided. The fluid outlet check valve 34 functions as an isolating check valve.

[0054] Furthermore, an internal check valve 28 is provided in the slidable piston 29 of the pressure intensifier

15. The internal check valve 28 allows a fluid flow from the inlet side 16 to the outlet side 17 of the pressure intensifier 15 in the beginning of a pressurisation phase, as long as the pressures at the inlet side 16 and the outlet side 17 are the same. As soon as a certain pressurisation in outlet chamber 32 is reached, the internal check valve 28 closes, so that the pressure in the outlet chamber 32 can raise over the pressure inside the inlet chamber 31 of the pressure intensifier 15. This way, a sufficient displacement of fluid towards the fluid outlet connector 3, and hence the test sample 2, can be effectuated.

[0055] Since the pressure intensifier 15 divides the fluid line, connecting the synthetically commutated hydraulic pump 4 to the fluid output connector 3, into sections with a different pressure level (medium-pressure line 9 and high-pressure line 10), due to the design of the pressure intensifier 15, the internal check valve 28 provides a physical fluid connection between the medium-pressure and the high-pressure lines. Internal check valve 28 functions as a pressure section separating check valve.

[0056] The high-pressure line 10 is pressurised indirectly by the synthetically commutated hydraulic pump 4. The pump raises pressure in medium-pressure line 9, which in turn is intensified leading to an even higher pressurisation in the high-pressure line 10, where the pressure in high-pressure line 10 is applied to the test sample 2.

[0057] Once the high fluid pressure has been applied (or has been held) to the test sample 2 for a sufficiently long time, the synthetically commutated hydraulic pump 4 is actuated by digital controller 6 in a way that no pumping is performed anymore towards the medium-pressure line 9. Due to the needle valve 20, the pressure in medium-pressure line 9 begins to drop slowly. Once a certain pressure level (decreasing pressure) has been reached, this pressure level exceeds (undercuts) the triggering pressure level of the pilot operated check valve 22 through triggering line 21. Therefore, once this triggering pressure of pilot operated check valve 22 has been reached, the pilot operated check valve 22 suddenly opens from its closed to its (fully) open state. Therefore, the (usually) essentially constant high-pressure plateau 38 of the pressure in high-pressure line 10 suddenly falls towards ambient pressure 40, since high-pressure line 10 is quickly vented to low-pressure line 8 and hence fluid reservoir 11.

[0058] The accumulator is permanently fluidly connected to the intermediate resetting chamber 27, which during the depressurisation period 40 of the test device 1 when the synthetically commutated hydraulic pump 4 is not pumping, provides a biasing force on the slidable piston 29 towards its standby position during the depressurisation, which causes an accelerated retraction motion of the slidable piston 29. It is to be noted that, while the pressure in the medium-pressure line 9 drops after the pumping of the synthetically commutated hydraulic pump 4 has been stopped, the pressure in the accumulator line 23/in the fluid accumulator 24 essentially re-

mains at a constant pressure level determined in part by the medium line pressure and the pressure drop across fluid flux limiting valve 26, thanks to the accumulator check valve 25.

[0059] Fig. 3 shows a possible series 35 of pressure pulses 36 of a certain shape that can be generated using the presently proposed hydraulic arrangement 1 (or a modification thereof). Fig. 4 shows schematically the flows in the hydraulic system of the test device 1 for a single pressure pulse 36.

[0060] Each pressure pulse 36 can essentially be divided into three (or four, when including the dwell phase 40 or ambient pressure phase) parts, namely a pressure increasing flank 37, a high-pressure plateau 38 and a pressure decreasing flank 39, followed by a dwell phase 40, where the pressure is essentially at ambient pressure. After the dwell phase 40 another pressure pulse 36 is initiated.

[0061] To initiate a pressure increase of pressure increasing flank 37, the synthetically commutated hydraulic pump 4 is actuated in a way that a certain fluid pumping rate towards the medium-pressure line 9 is effectuated, where the pumping rate depends on the slope of the pressure increasing flank 37 to be realised (and also on fluid losses, in particular through needle valve 20, through internal check valve 28 towards the high-pressure line 10 (beginning of the pressurisation cycle) and through accumulator check valve 25 towards accumulator line 23). It is to be noted that the pressure in medium-pressure line 9 is measured by a first pressure sensor 18. If the fluid losses vary during the pressurisation phase 37, thanks to the characteristics of the synthetically commutated hydraulic pump 4 the pumped fluid flux can be quickly adapted to the new fluid flow requirements.

[0062] As can be seen in Fig. 4, the pumping rate 41 of synthetically commutated hydraulic pump 4 is quickly rising once a pumping of the synthetically commutated hydraulic pump 4 has been initiated. Consequently, the pressure 42 in medium-pressure line 9 is increasing, which leads also to a rise of the pressure 43 in high-pressure line 10 (upper graph of Fig. 4). Due to the presence of the pressure intensifier 15, the two pressures 42, 43 in medium-pressure line 9 and high-pressure line 10 diverge after a short time. With increasing pressure 40 in medium-pressure line 9, the fluid flow 44 through needle valve 20 increases appropriately. The pilot operated check valve 22, however, is fully closed, so that the fluid flow 45 through pilot operated check valve 22 is essentially zero.

[0063] Once the cut-off time 46 has been reached (changeover from pressure increasing flank 37 to high-pressure plateau 38 of the pressure pulse 36), the synthetically commutated hydraulic pump 4 is controlled so that no pumping is performed anymore towards the medium-pressure line 9. As a result, the pressure 43 in high-pressure line 10 remains at the maximum pressure, namely the plateau pressure 38. The pressure 42 in medium-pressure line 9, however, starts to drop after the

cut-off time 46.

[0064] Once the triggering pressure 48 has been reached in the medium-pressure line 9 (occurring at cracking time 47; this is equivalent to the changeover from high-pressure plateau 38 to pressure decreasing flank 39 of pressure pulse 36) the pilot operated check valve 22 cracks open and therefore the pressure 37 in high-pressure line 10 drops sharply due to the significant fluid flow 45 through pilot operated check valve 22. This forms the pressure decreasing flank 39, where the slope of the pressure decreasing flank 39 can be varied by changing the size of the orifice of the pilot operated check valve 22.

[0065] Fig. 5 shows a schematic circuitry of a possible second embodiment of a test device 49 for generating a series 35 of periodic fluid pressure pulses 36. This test device 49 is a variation of the test device 1, as shown in Fig. 1 and as described above. For simplicity, for identical and (highly) similar parts, the same reference numerals are used. Furthermore, reference is made to the already made explanations.

[0066] Contrary to the test device 1 according to Fig. 1, the presently shown test device 49 has no pressure intensifier. Therefore, there is no requirement for an arrangement for returning a slidable piston of such pressure intensifier. Therefore, the accumulator, the accumulator line, and the accompanying parts thereof can be dispensed with. It is obvious that this constitutes a variation of the arrangement of the test device 49.

[0067] Presently, a check valve 50 is used (functional section separating check valve), that separates the fluid conduit into a first part of the fluid conduit 51 and a second part of the fluid conduit 52. This separation into two functional parts of the fluid conduit 51, 52 is necessary, to maintain the previously described depressurisation functionality of the fluid pressure applied to the test sample 2 (fluid pressure in the second part of fluid conduit 52), using a pilot operated check valve 22. If no such check valve 50 were present, the pressure in the first part of the fluid conduit 51 could not drop below the pressure in the second part of the fluid conduit 52 by setting the synthetically commutated hydraulic pump 4 to an idle mode (no pumping), allowing the needle valve 22 to release pressurised fluid in first part of the fluid conduit 51 towards low-pressure line 8/fluid reservoir 11. Therefore, the (flat) pressure plateau 38 at the fluid output connector 3 could not be maintained during this phase.

[0068] Based on the decrease of pressure in the first part of the fluid conduit 51 (and therefore in triggering line 21) towards triggering pressure, the pilot operated check valve 22 will quickly switch open, once the triggering pressure is reached, as previously described.

[0069] It is therefore obvious to person skilled in the art, that the functionality of both test devices 1, 49 according to Fig. 1 and Fig. 5, respectively, is quite similar to each other.

[0070] A certain drawback of the design of the test device 49 according to Fig. 5 is that the maximum pressure

at the fluid output connector 3 will be essentially the same as the maximum pressure that is generated by the synthetically commutated hydraulic pump 4. In principle, this is not necessarily a major disadvantage, since the design of synthetically commutated hydraulic pumps 4 allows pumps to be built that have a very high achievable output pressure. Nevertheless, the high output pressure that has to be created by the synthetically commutated hydraulic pump 4 might increase the wear of the synthetically commutated hydraulic pump 4. Also, if the output pressure required at fluid output connector 3 exceeds the capability of the present test device 49, it may be necessary to revert to a design with a pressure intensifier.

[0071] Fig. 6 shows a graph that plots a possible fluid output flow 54 over time for a synthetically commutated hydraulic pump 4, if an actuation scheme according to Fig. 7 is applied (as described below). If such a fluid output flow 54 is supplied to the previously described test devices 1, 49 (and different designs as well), based on the design and the functionality of the test devices 1, 49, a series 35 of periodic fluid pressure pulses 36 will be realized.

[0072] As one can see, the synthetically commutated hydraulic pump 4 (presently the synthetically commutated hydraulic pump comprises a plurality of cylinders) is alternately actuated in a full pumping actuation scheme 55 and an idling actuation scheme 56.

[0073] In the full pumping actuation scheme 55, the actuated inlet valves of the pumping chambers of the synthetically commutated hydraulic pump 4 are closed at the bottom dead centre of the piston's movement. This results in a full pumping stroke (100%) of the displacement is pumped towards the high-pressure (medium-pressure) fluid outlet side of the synthetically commutated hydraulic pump 4. Due to the operational characteristics of synthetically commutated hydraulic pumps 4, the fluid output flow 54 shows a sharp increase at the beginning of a full pumping actuation scheme 55, a sharp decrease at the end of a full pumping actuation scheme 55, and an essentially uniform output at the top plateau phase of the full pumping actuation scheme 55. During this scheme 55, the pressure buildup will occur at the fluid outlet connector 3.

[0074] During the idling actuation scheme 56, the medium-pressure line 9/the first part of the fluid conduit 51 will start to depressurise due to the fluid loss induced by the needle valve 20, while the high-pressure line 10/the second part of the fluid conduit 52 initially remains at top pressure. Once the triggering pressure of pilot operated check valve 22 is reached, the pressure in the high-pressure line 10/the second part of the fluid conduit 52 will drop sharply.

[0075] Since the slow depressurisation of medium-pressure line 9/the first part of the fluid conduit 51, after having stopped the full pumping actuation scheme 55 and before the triggering pressure for the pilot operated check valve 22 is reached, takes some time, the temporal length of the full pumping actuation scheme 55 is chosen

to be shorter than that of the idling actuation scheme 56, to realise a series of pressure pulses with essentially identical lengths of high-pressure plateaus and ambient pressure phases (dwell times).

[0076] Fig. 7 shows a schematic flow chart 57 of a possible method of performing a test cycle for test samples 2 that are connected to the fluid output connector 3 of a test device 1 according to Fig. 1 or a test device 49 according to Fig. 5, for example.

[0077] Once the mechanical setup is completed, the test cycle is started (step 58). A certain, usually predetermined, number of pumping strokes of the synthetically commutated hydraulic pump 4 is applied (step 59). These pumping strokes may be full (100%) or part pumping strokes (greater than 0% and less than 100%).

[0078] Following this full pumping actuation scheme 55, an idling actuation scheme 56 is applied, namely a certain, usually predetermined, number of idle strokes is applied (step 61).

[0079] Usually, the number of idling strokes during step 61 is larger than the number of full pumping strokes of step 59, for the reasons described above.

[0080] Optionally, the correct number of full pumping strokes and/or idling strokes during step 59 and 61 can be verified by measuring the pressure(s) in a pressurised fluid conduit (step 60, 62), in particular in the medium-pressure line 9 and/or the high-pressure line 10 of test device 1, or in the first part of fluid conduit 51 and/or in the second part of fluid conduit 52 of test device 49, using one or several pressure sensors 18, 33.

[0081] It is to be noted that the pressure measurement(s) can be performed in parallel to applying the full pumping strokes 59 and/or the idle strokes 61. Also, it is possible to measure the pressure(s) after applying the respective cycle of full pumping strokes 59 and/or idle strokes 61, and to correct the respective number of strokes in the next pressurisation-depressurisation-cycle.

[0082] After the certain number of idle strokes has been reached in step 62, it is determined in step 63 whether the total number of periodic fluid pressure pulses (36) of the test cycle has reached the predetermined number of pressurisation-depressurisation cycles of the series (35). If this is the case, the test cycle stops at step 64. If this is not the case, the path jumps back 65 to perform more pumping and idling strokes 59 and 61.

[0083] It is to be noted that a single one or a plurality of the features of the presently disclosed detailed embodiment may be used in combination with the generic description of the present disclosure.

Claims

1. Hydraulic arrangement (1, 49) for generating a series (35) of periodic fluid pressure pulses (36), comprising a synthetically commutated hydraulic pump (4), a fluid output connector (3) for an external device

(2), a fluid conduit (9, 10, 51, 52) connecting said synthetically commutated hydraulic pump (4) and said fluid output connector (3), a triggerable orifice device arrangement (22) connected to said fluid conduit (9, 10, 51, 52), at least a pressure transducer (18, 33) being fluidly connected to said fluid conduit (9, 10, 51, 52), and a control device (6) for controlling said hydraulic arrangement (1, 49).

2. Hydraulic arrangement (1, 49) according to claim 1, **characterised in that** said triggerable orifice device arrangement (22) comprises a trigger valve unit that can be triggered using an external signal, wherein said trigger valve unit can be triggered electrically, mechanically and/or fluidly, and wherein said trigger valve unit is preferably designed as a pilot operated check valve.

3. Hydraulic arrangement (1, 49) according to claim 1 or claim 2, in particular according to claim 2, **characterised in that** the triggerable orifice device arrangement (22) comprises an orifice with a variable size, wherein the size of the orifice can be preferably controlled by the control device (6) and/or by varying a mechanical orifice.

4. Hydraulic arrangement (1, 49) according to any of the preceding claims, **characterised in that** the fluid conduit (9, 10) comprises a pressure intensifier device (15), wherein the pressure intensifier device (15) divides the fluid conduit in a medium-pressure fluid conduit (9) and a high-pressure fluid conduit (10), wherein the pressure intensifier device (15) preferably provides, at least at times, a physical fluid connection between said medium-pressure fluid conduit (9) and said high-pressure fluid conduit (10).

5. Hydraulic arrangement (1, 49) according to any of the preceding claims, in particular according to claim 4, **characterised by** a check valve (28, 50) that is arranged in the fluid conduit (9, 10, 51, 52), in particular a check valve (28) that is arranged between the medium-pressure fluid conduit (9) and the high-pressure fluid conduit (10), more preferably being arranged as a part (28) of the pressure intensifier device (15), and/or a check valve (50) that is arranged between a first part of the fluid conduit (51) and a second part of the fluid conduit (52), wherein the first part of the fluid conduit (51) is neighbouring the synthetically commutated hydraulic pump (4) and the second part of the fluid conduit (52) is neighbouring fluid output connector (3).

6. Hydraulic arrangement (1, 49) according to any of the preceding claims, in particular according to claim 4 or 5, **characterised in that** the triggerable orifice device arrangement (22), in particular the trigger valve unit, is triggered by fluid pressure in the fluid

conduit part (9, 51) between the synthetically commutated hydraulic pump (4) and the check valve (28, 50) and/or by the fluid pressure in the medium-pressure fluid conduit (9), and/or by the fluid pressure in the first part of the fluid conduit (51).

7. Hydraulic arrangement (1, 49) according to any of the preceding claims, in particular according to any of claim 4 to 7, **characterised by** a fluid flux valve (20) that is connected to the fluid conduit (9, 10, 51, 52), preferably to the fluid conduit part (9, 51) between the synthetically commutated hydraulic pump (4) and the check valve (28, 50) and/or to the medium-pressure fluid conduit (9) and/or to the first part of the fluid conduit (51), wherein the low fluid flux throughput valve (22) is preferably a needle valve (22).
8. Hydraulic arrangement (1) according to any of the preceding claims, in particular according to any of claims 5 to 8, **characterised by** at least a fluid accumulator (24) that is at least at times fluidly connected to a part of the hydraulic arrangement (1) that is at least at times at an elevated pressure level (9, 10, 51, 52), wherein said fluid accumulator (24) is preferably connected to a movable device (29) of the hydraulic arrangement (1) to move said movable device (29) to a defined position.
9. Hydraulic arrangement (1, 49) according to claim 8, **characterised in that** the pressure accumulator (24) is fluidly connected to the fluid conduit (9, 10), preferably to the fluid conduit part (9) between the synthetically commutated hydraulic pump (4) and the check valve (28,) and/or to the fluid conduit part (9) between the synthetically commutated hydraulic pump (9) and the pressure intensifier device (15) and/or or to the medium-pressure fluid conduit (9) and/or to the first part of the fluid conduit (9), by means of an accumulator check valve (25) and possibly a fluid flux limiting valve (26).
10. Hydraulic arrangement according to any of the preceding claims, **characterised in that** the hydraulic arrangement (1, 49) is designed and arranged in a way to provide a series (35) of periodic fluid pressure pulses (36) with a frequency above 0 Hz, preferably at least 1 Hz, more preferably at least 3 Hz.
11. Hydraulic arrangement (1, 49) according to any of the preceding claims, **characterised in that** the hydraulic arrangement (1, 49) is designed and arranged to provide a pressure at the fluid output connector (3) of at least 350, preferably at least 400, more preferably at least 450, and even more preferably at least above 500 bar.
12. Use of a hydraulic arrangement (1, 49) according to

any of the preceding claims as a test device (1, 49) for hydraulic components (2).

13. Method (57) of generating a series (35) of periodic fluid pressure pulses, **characterised in that** a hydraulic arrangement (1, 49) according to any of claims 1 to 12 is used.
14. Method (57) of generating a series (35) of periodic fluid pressure pulses, in particular method (57) according to claim 13, **characterised in that** the series (35) of periodic fluid pressure pulses (36) is preferably primarily controlled by alternately applying a series of a defined number of pumping strokes (59) of the synthetically commutated hydraulic pump (4), followed by a series of a defined number of non-pumping strokes (61) of the synthetically commutated hydraulic pump (4).
15. Method according to claim 14, **characterised in that** the number of pumping cycles (59) and/or non-pumping cycles (61) differs from each other and/or is adapted (60, 62) using measurement data by the at least one pressure transducer (18, 33).

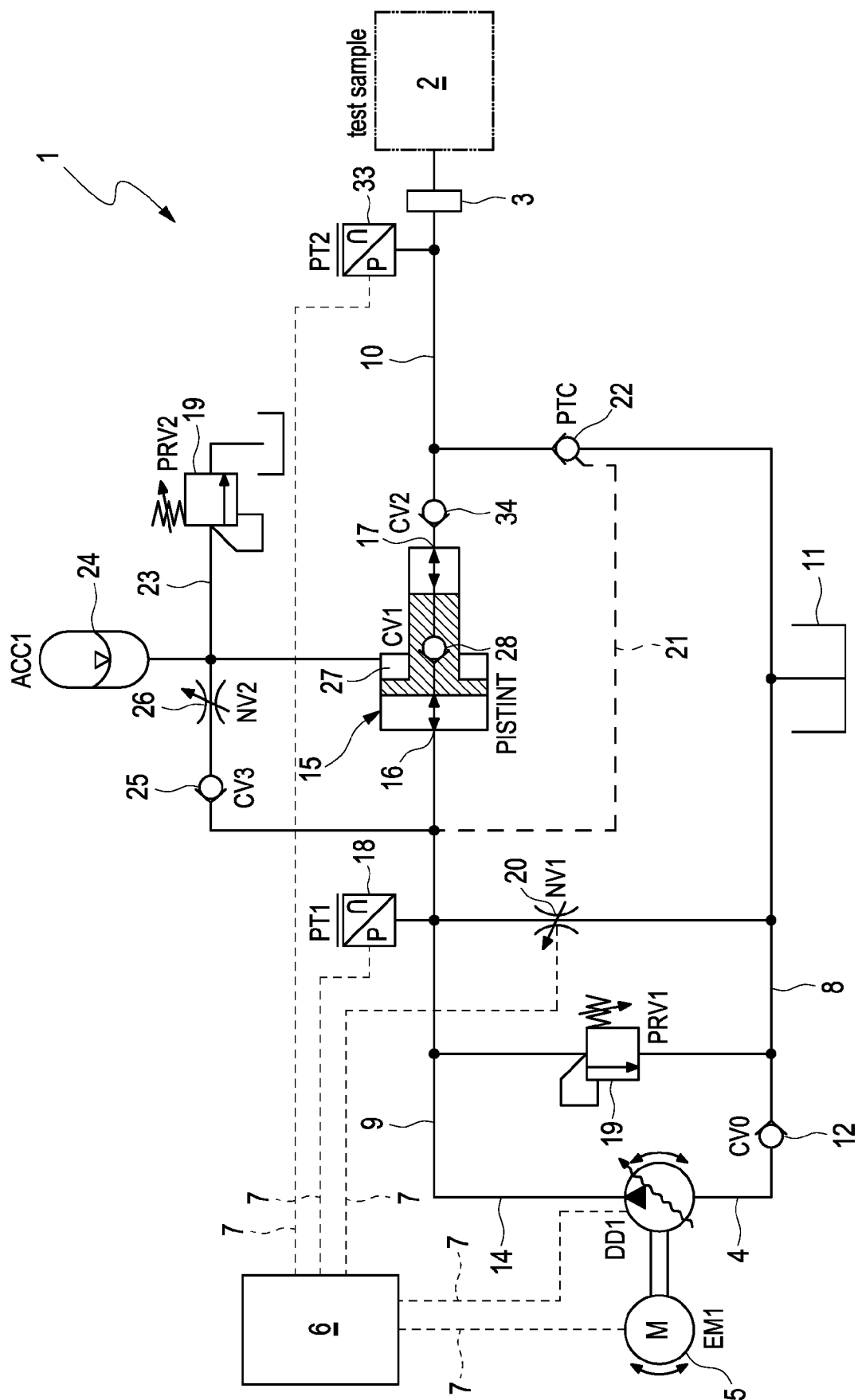


Fig. 1

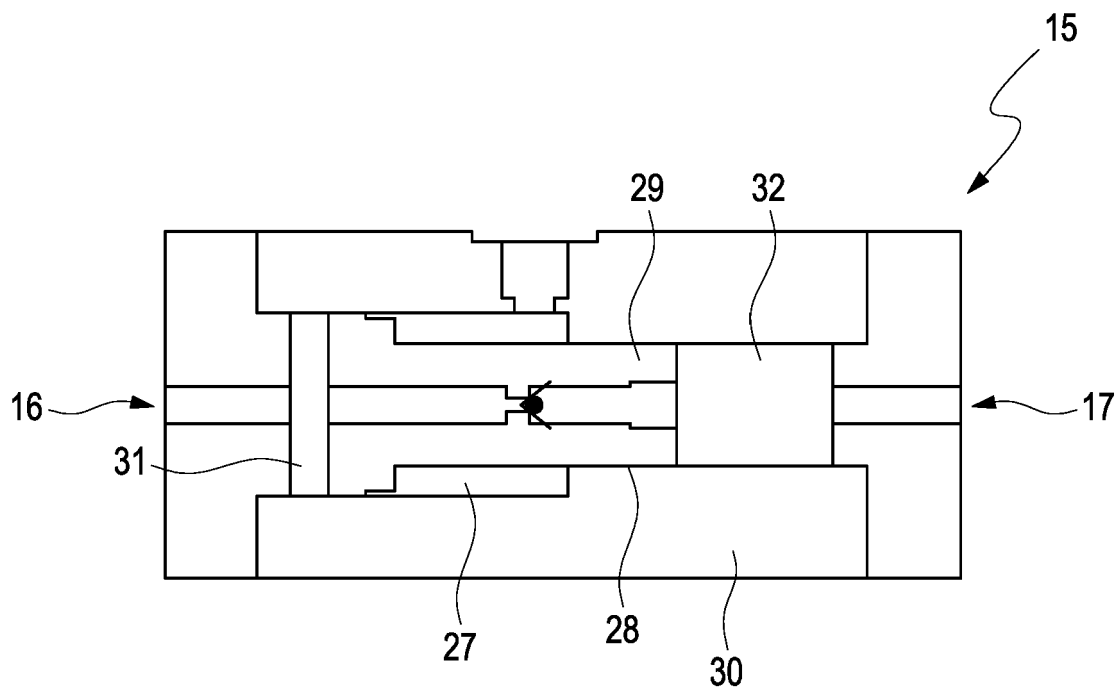


Fig. 2

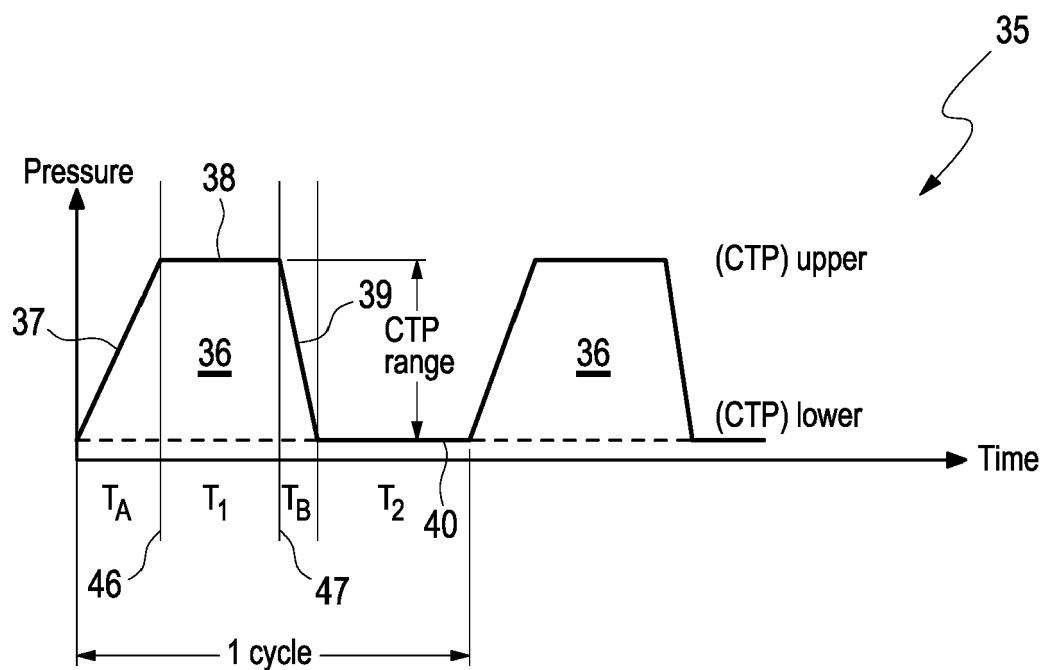


Fig. 3

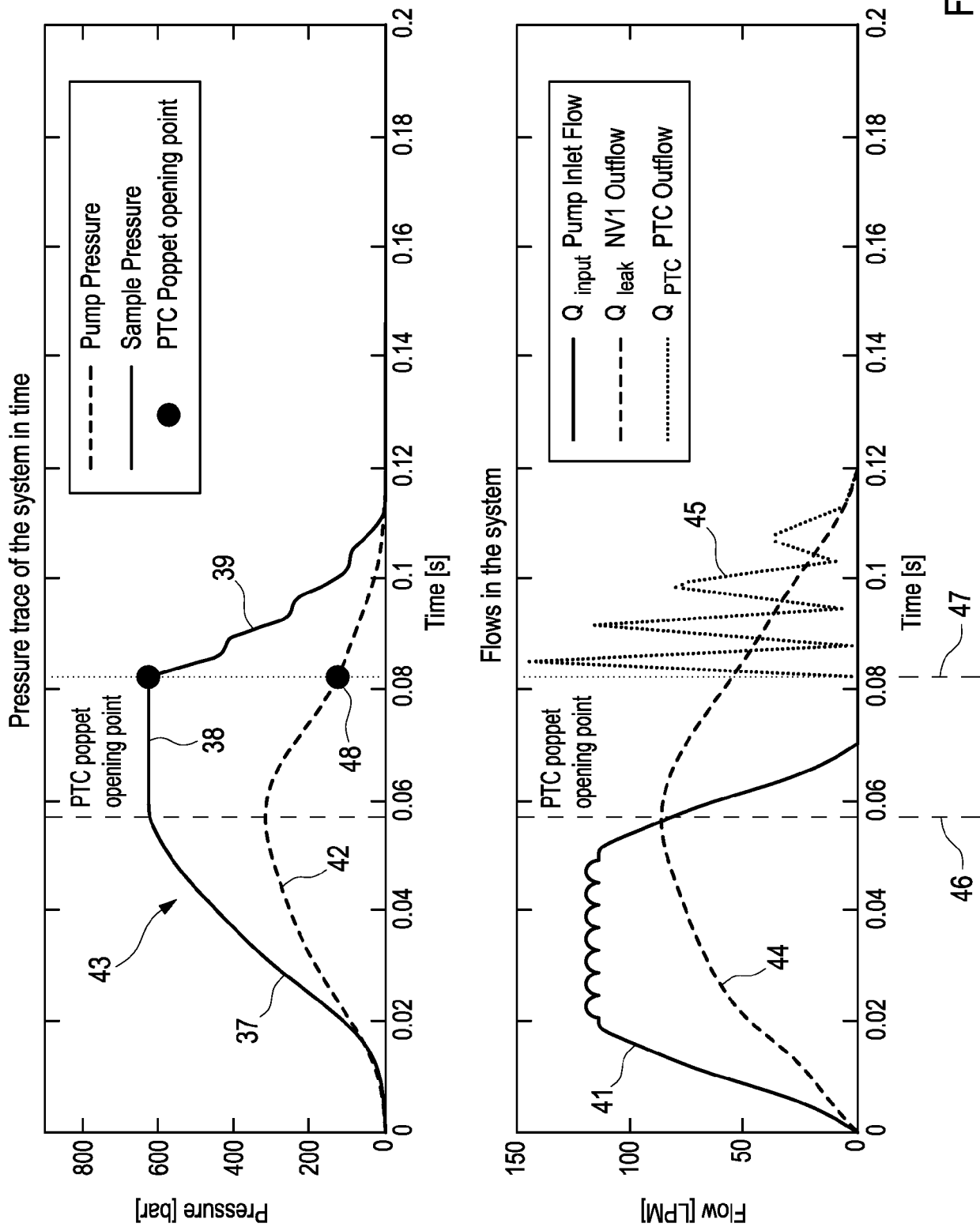


Fig. 4

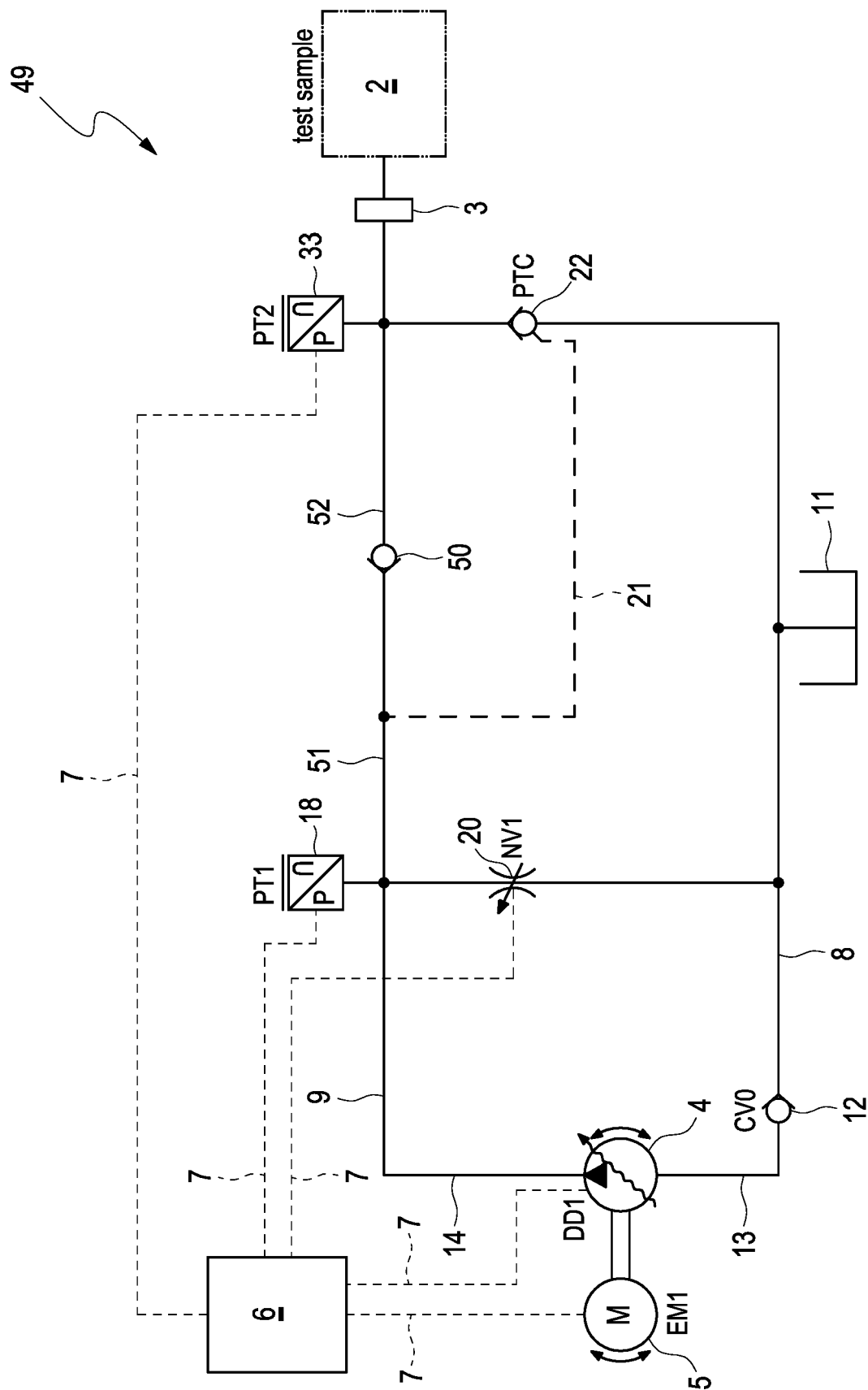


Fig. 5

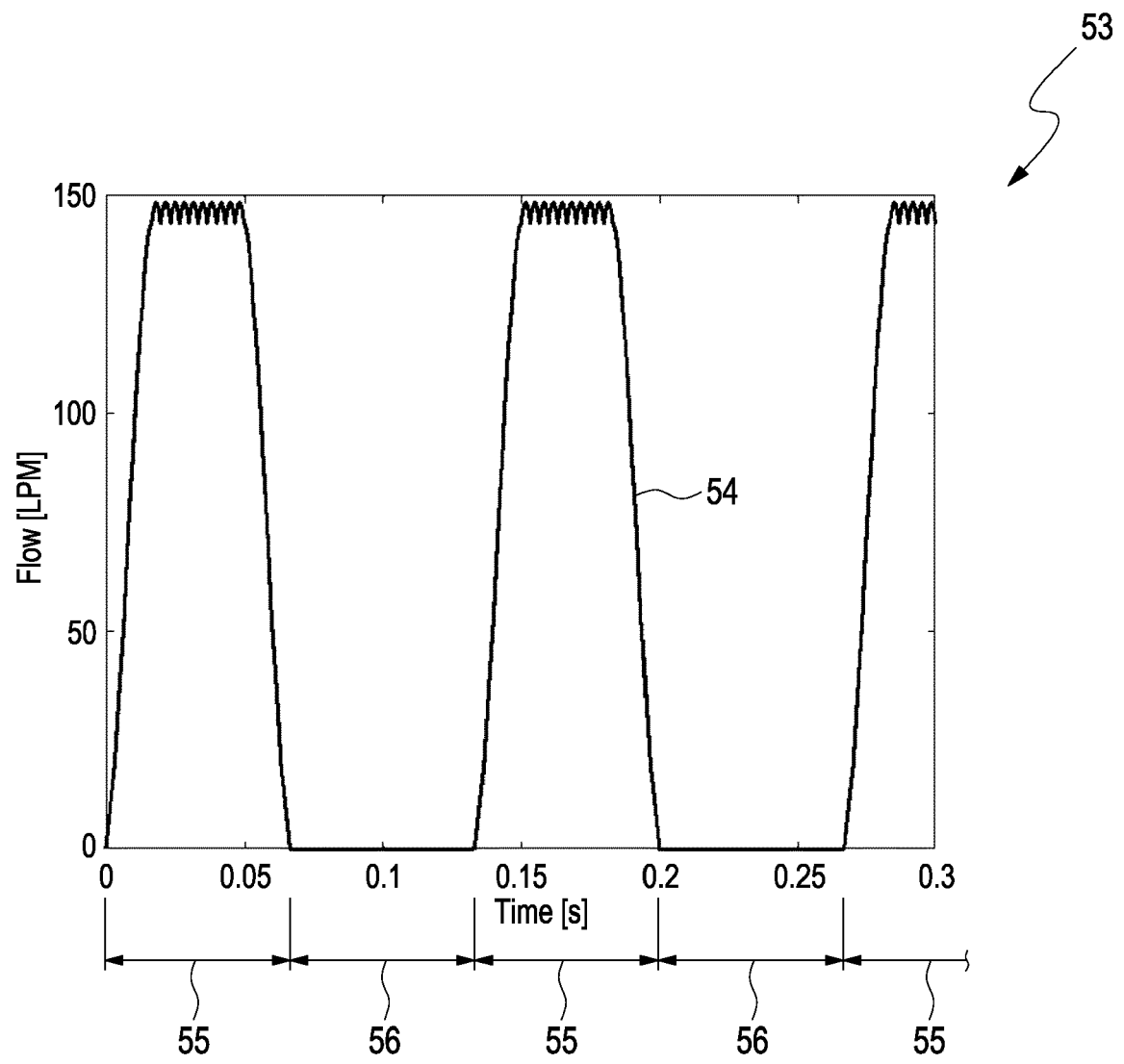


Fig. 6

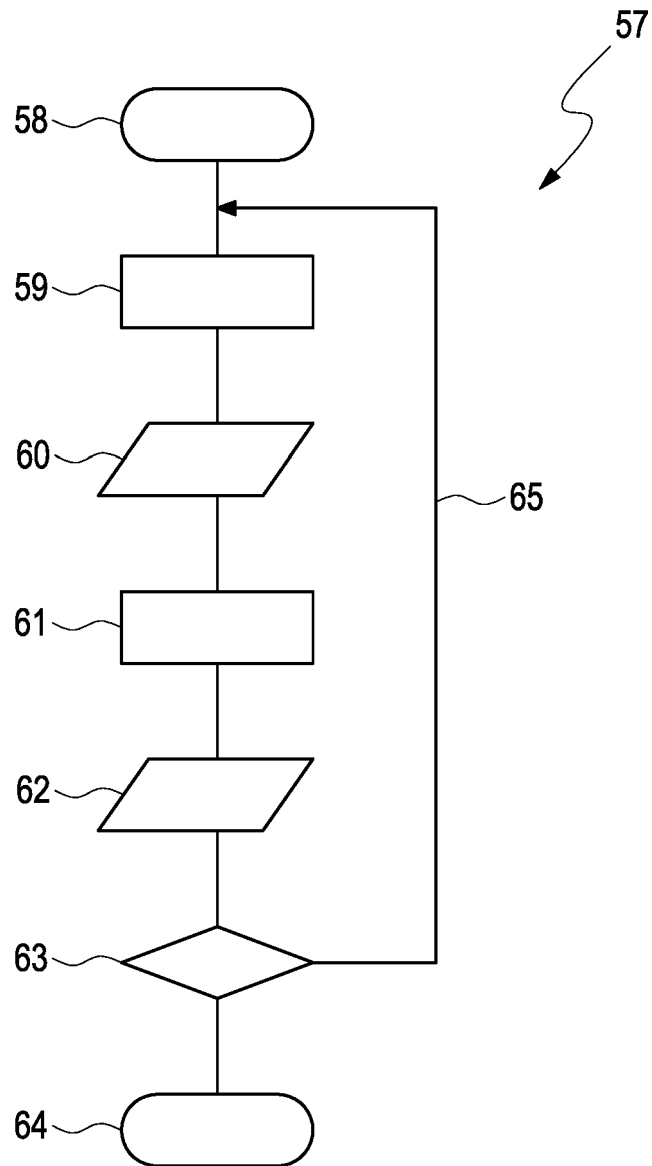


Fig. 7



EUROPEAN SEARCH REPORT

Application Number

EP 23 15 0629

5

10

15

20

25

30

35

40

45

50

55

1

EPO FORM 1503 03.82 (P04C01)

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	US 10 180 135 B2 (ARTEMIS INTELLIGENT POWER LTD. [GB]) 15 January 2019 (2019-01-15)	1-3, 5, 8-13	INV. F03C1/26 F04B1/06
A	* figures 1, 34, 35 * * column 1, line 34 - column 2, line 8 * * column 9, line 65 - column 12, line 26 * * column 20, line 40 - column 21, line 8 * -----	4, 6, 7, 14, 15	F04B7/00 F04B49/03 F04B49/22
X	"Synthetically Commutated Hydraulic Pump and Pump/Motor Applications ED - Darl Kuhn", IP.COM, IP.COM INC., WEST HENRIETTA, NY, US, 6 November 2008 (2008-11-06), XP013126813, ISSN: 1533-0001	1-3, 6, 8-13	
A	* page 16/21; figure 5 * * page 20/21; figure 8 * -----	4, 5, 7, 14, 15	
A	US 2015/345489 A1 (DANFOSS POWER SOLUTIONS GMBH & CO. OHG [DE]) 3 December 2015 (2015-12-03) * figure 1 * * paragraphs [0009], [0010] * * paragraph [0033] - paragraph [0044] * -----	1-15	TECHNICAL FIELDS SEARCHED (IPC) F03C F04B
The present search report has been drawn up for all claims			
Place of search Munich		Date of completion of the search 15 June 2023	Examiner Gnüchtel, Frank
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	

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

EP 23 15 0629

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.

15-06-2023

10	Patent document cited in search report	Publication date	Patent family member(s)	Publication date
15	US 10180135 B2	15-01-2019	EP 3201474 A1	09-08-2017
			GB 2529909 A	09-03-2016
			JP 6728145 B2	22-07-2020
			JP 2017531769 A	26-10-2017
			US 2017284388 A1	05-10-2017
			WO 2016051172 A1	07-04-2016
20	US 2015345489 A1	03-12-2015	CN 104854346 A	19-08-2015
			DE 102012109074 A1	27-03-2014
			DE 112013004734 A5	03-06-2015
			EP 2912309 A1	02-09-2015
			JP 6063048 B2	18-01-2017
			JP 2015533984 A	26-11-2015
			US 2015345489 A1	03-12-2015
			WO 2014048418 A1	03-04-2014
30				
35				
40				
45				
50				
55				

ORM P0459