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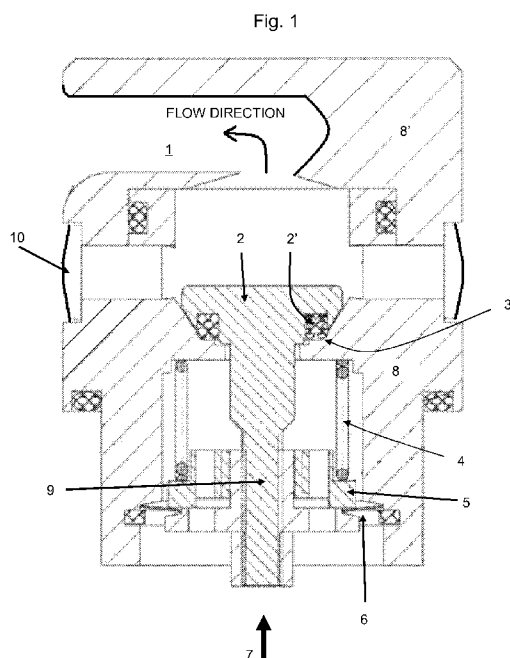
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(54) Title: A RELIEF VALVE



(57) Abstract: The invention relates to a relief valve in particular a gas relief valve. The relief valve comprises a house with an inlet side and an outlet side, a seat and a sealing element displaceable with respect to each other, and a first and a second spring element. The relief valve has a closed position and an open position. The sealing element rests on the said seat when the relief valve is in its closed position and the sealing element is displaced with respect to said seat to provide passage from said inlet side to said outlet side when the said relief valve is in its open position. The first and the second spring elements are arranged to apply a closing pressure when the relief valve is in its closed position. The first spring element is a linear operating spring element, such as a coil spring and the said second spring element is a nonlinear operating spring element, such as a disc spring. The relief valve of the invention provides a strong snap-open/closure effect, capable of operating with a desired pressure difference between the high pressure side and the low pressure side.

A RELIEF VALVE

TECHNICAL FIELD

The present invention relates to a relief valve for use in fluid systems in order to control fluid flow and/or to alleviate excessive and undesired pressure
5 and/or to avoid generation of undesirable high pressure.

BACKGROUND ART

Pressure relief valves are important components in the fluid processing industry as well as in the oil and gas industry to control fluid flow or to alleviate excessive and undesired pressure and/or to avoid generation of undesirable
10 high pressure. In such fluid systems, overpressure can damage valuable equipment, cause breakdown or rupture of weak components of the system and/or result in danger to people near the system. In many systems it is desirable that when a pre-determined or pre-designated threshold pressure is exceeded, the pressure relief valve opens very quickly, i.e., virtually
15 instantaneously, to relief system pressure. Pressure relief valves having this capability are commonly referred to as "pop-off" valves or snap valves because of their rapid opening action.

US 6,516,828 discloses a traditional relief valve comprising a seat and a sealing element and a coil spring pressing the sealing element to rest on the
20 seat. The described relief valve has a specially formed chamber on the low pressure side to adjust the outflow. US 6,095,183 discloses a similar valve which comprises the additional feature that the sealing element comprises a flange which extends such that a back-pressure will act on it for fast closing of the valve.

25 The prior art coil spring operating relief valves are generally linear operated. When system-pressure increases on the high pressure side, the pressure driven sealing element gradually balances and increases a pre-set spring force value. In order to separate the sealing element from the seat the pressure provided from the high pressure side needs to overcome the pre-set
30 spring force value whereby the sealing element will separate from the seat

and fluid will pass by, which results in an immediately pressure relief. This pressure relief results in a reduced pressure on the high pressure side which very fast will result in that the high pressure side no longer overcomes the pre-set spring force value and the sealing element will again rest on the seat and the whole process will repeat itself. In order to fully open the relief valve additional pressure than the pressure for open the pre-set spring force is needed. In practice this means that only pressure pulses will open the relief valve fully. Accordingly in many applications the relief valve will never be fully open, but often it will be slightly open with a high close-slightly open frequency or if the fluid comprises solids such solids may easily block the relief valve from closing at all.

A relief valve designed for such use in pipelines where small particles may be present is described in US 6,152,170. The relief valve which is denoted 'a differential valve' comprises a double valve structure comprising two seat-sealing element valve structures, each comprising a coil spring pressing the sealing element to rest on the seat. The two seat-sealing element valve structures have different set-pressures for opening and closing.

Another type of relief valve is disclosed in US 6,250,329. The relief valve disclosed herein is a snap open relief valve based on a disk spring. The valve comprises a seat and a sealing element and a disc spring pressing the sealing element to rest on the seat.

The object of the invention is to provide an improved relief valve which provides a strong snap-open/closure effect, capable of operating with a desired pressure difference between the high pressure side and the low pressure side.

The relief valve according to the invention has been found to fully solve this object. Due to the special construction comprising a linear spring and a nonlinear spring element, the relief valve of the invention will either be fully or almost fully open or it will be fully closed.

The combination of the two spring elements has shown to provide a strong snap-open/closure effect, capable of operating with a desired pressure difference between the high pressure side (inlet side) and the low pressure side (outlet side).

- 5 The relief valve of the invention comprises a house with an inlet side and an outlet side. The inlet side is also called the high pressure side of the relief valve and the outlet side is also referred to as the low pressures side of the valve. As long as the pressure on the high pressure side is lower than a set point of the valve, the valve will be closed. When the pressure on the high
10 pressure side reaches a set point, the valve and fluid can pass from the high pressure side (the inlet side) to the low pressure side (the outlet side).

The relief valve further comprises a seat and a sealing element displaceable with respect to each other. The relief valve comprises a closed position and an open position, where the sealing element rests on said seat when the relief
15 valve is in its closed position and the sealing element is displaced with respect to said seat to provide passage from said inlet side to said outlet side when the relief valve is in its open position.

The relief valve of the invention furthermore comprises at least a first and a second spring element, which first and said second spring elements are
20 arranged to apply a closing pressure when the relief valve is in its closed position.

The house as well as the seat and the sealing element may have any shape e.g. as shaped in the prior art relief valves. The shape and size of the house may preferably be adapted to the expected use of the relief valve. In one
25 embodiment the house comprises a hollow body with an inlet side and an outlet side opposite to each other. In another embodiment the house comprises an angled hollow body inlet side and outlet side on respective sides of the angle. In one embodiment the size of the house is relatively small such as a house with a volume of about 25 cm³ or less, such as with a
30 volume of about 10 cm³ or less with a volume of about 5 cm³ or less with a volume of about 2,5 cm³ or less. Valves with such relative small volumes are

in particular useful for gas relief valves, but they may in certain applications also be useful in relief valves involving other fluids such as mixtures of gas and liquids as well as supercritical fluids. In one embodiment the size of the house is much larger, e.g. up to about 1 m³ or even larger. The shape and the size of the seat and the sealing element are not important as long as the seat and the sealing element are adapted to each other to provide a sufficient closure of the valve when the sealing element rests on said seat, and to provide a passage from the inlet side to the outlet side of the valve when the sealing element is displaced with respect to said seat. It should be understood that the displacement of the sealing element with respect to the seat is meant to be a relative displacement, which may e.g. be caused by movements of both the seat and the sealing element or by one of the seat and the sealing element. In one embodiment the sealing element is fixed and the seat is movable. In another embodiment the seat is fixed and the sealing element is movable. In a third embodiment both the seat and the sealing element are movable. The size of the seat and the sealing element may preferably be selected in relation to the expected use of the valve. The size of the seat and the sealing element should naturally also be selected in relation to the size of the house, preferably such that the seat and the sealing element have sizes such that they fit inside the house.

In one embodiment the sealing element is a sealing disk member and the seat is an annular seat member. The sealing disk member may for example be connected to a valve rod. One or more of the spring elements may act directly on the sealing disk member, directly on the valve rod or indirectly on the sealing element and/or the valve rod e.g. via one or more additional valve elements interacting with the sealing element and/or the valve rod when the valve is in operation.

In one embodiment where both the seat and the sealing element are movable, the spring elements act directly or indirectly e.g. via one or more additional valve elements on the movable seat and/or on the movable sealing element. For example the first spring element may act directly or indirectly on the movable seat and the second spring element may act directly on the movable

sealing element or visa verse, or both spring elements may act directly or indirectly on one of the movable seat and the movable sealing element, or one or more of the spring elements may act directly or indirectly on both the movable seat and the movable sealing element.

- 5 In one embodiment where only one of the seat and the sealing element is movable, the spring elements act directly or indirectly e.g. via one or more additional valve elements on the movable seat or sealing element.

In one embodiment the first and the second spring element independently of each other apply a closing pressure when the relief valve is in its closed
10 position. Preferably the first and the second spring element are operating independently of each other on one or both of the movable seat and the movable sealing element. In other words, although the forces applied by the respective spring elements are influencing the whole valve status (open or closed), the spring elements are in this embodiment individual spring
15 elements and individual operating spring elements.

In the relief valve of the invention the first spring element is a linear operating spring element which means that it is operating substantially linear within the operation range of the relief valve; and the second spring element is a
nonlinear operating spring element which means that the second spring
20 element is not operating substantially linear within the operation range of the relief valve.

The term "the operation range of the relief valve" is used to mean the range from the relief valve is unloaded and fully closed to the relief valve is fully open and back to its fully unloaded state. In other words, the force within the
25 operation range of the relief valve is from about 0 to about the total force required to open the relief valve fully. The total force required to open the relief valve fully is also referred to as the relief valve set point force.

The term "the operation range of spring element" is used to mean the range from the spring element is unloaded and until the relief valve is fully open and
30 back to the fully unloaded state of said specific spring element. In other words,

the force within the operation range of a specific spring element is from about 0 to about the force applied onto said specific spring element when the total force required to open the relief valve fully is applied. The force applied onto a specific spring element when the total force required to open the relief valve
5 fully is applied, is also referred to as the spring element set point force for said specific spring element.

In one embodiment the relief valve set point force is about the sum of the spring element set point forces for the two or more specific spring elements of
10 the relief valve.

In one embodiment the relief valve set point force is less than the sum of the spring element set point forces for the two or more specific spring elements of the relief valve. The relief valve set point force may for example be up to about 50 %, such as up to about 25 %, such as up to about 10 % less than
15 the sum of the spring element set point forces for the two or more specific spring elements of the relief valve.

Whether or not the relief valve set point force is less than the sum of the spring element set point forces for the two or more specific spring elements of the relief valve depends largely on the type of spring elements and the
20 structure of the relief valve and the interaction of the spring elements with the seat and/or sealing element.

In most situations the relief valve set point force will be in the interval about the sum of the spring element set point forces for the two or more specific spring elements of the relief valve to about 10 % less than the sum of the
25 spring element set point forces for the two or more specific spring elements of the relief valve.

In one embodiment the linear operating spring element is connected to one of said sealing element and said seat in a non-elastic connection.

In one embodiment the linear operating spring element is connected to at least one of said sealing element and said seat in an elastic connection, the elastic connection preferably being provided by a secondary linear spring with a K value (Spring Constant) higher than the value of the linear operating
5 spring element.

Several other structures of the linear operating spring element and the nonlinear operating spring element are available for the skilled person to use within the framework of the present invention.

10 The linear operating spring element may be any type of linear operating spring element which can operate within the desired operation force interval, i.e. which is operating essentially linear within the force interval from about 0 to about the spring element set point force for said specific linear operating spring element.

15 In one embodiment the linear operating spring element is a compression spring, preferably a coiled spring, such as a helical spring.

In a preferred embodiment the linear operating spring element is following Hookes law ($F1 = -K1 \cdot X1$) in its operation range, wherein

$F1$ = Force (N) exerted by the spring element,

20 $K1$ = Spring Constant (N/mm),

$X1$ = Displacement (mm) from equilibrium position.

The force exerted by the spring element in dependence of the displacement from equilibrium position $F1/X1$, the Spring Constant ($K1$), as well as the operation range of the spring element may have any desired value and should
25 preferably be selected in dependence of the desired use of the relief valve, the desired set point of the relief valve as well as the desired spring element set point force for said specific spring element.

The set point for the relief valve means the pressure set point at which pressure on the high pressure side of the relief valve is sufficient and at most sufficient to provide that the relief valve should be fully open.

5 In one embodiment the spring constant (K_1) is up to about 30 N/mm, such as from about 0.5 to about 25 N/mm, such as from about 0.8 to about 10 N/mm, such as from about 1 to about 3 N/mm, e.g. about 1.3 N/mm. The relief valve of this embodiment is for example useful as relief valve in an off-shore system e.g. a flexible pipe system.

10 The relief valve of the invention may in one embodiment comprise two or more linear operating spring elements which linear operating spring elements may be identical or they may be different from each other. Often for prolonging lifetime and for reducing risk of malfunction it may be desired that the relief valve of the invention comprises two or more, such 3, 4 or 8 linear operating spring elements. If one of the linear operating spring elements in
15 such a construction ceases to operate fully or partly, the relief valve may continue to operate with only a slight change of set point.

In one embodiment of the relief valve the linear operating spring element (or linear operating spring elements if there are several) is pre-tensioned when the sealing element rests on the seat. It is generally known to pre-tension
20 spring elements, and the skilled person will know how to establish and regulate such a pre-tensioning on the linear operating spring element(s).

The pre-tensioning adds to providing a safe sealing between the seat and the sealing element when the relief valve is in its closed position. Furthermore the pre-tensioning results in a reduced or totally avoids a displacement of the
25 sealing element relatively to the seat until the force applied to the pre-tensioned spring element has been overcome. Thereby the risk of a situation where the relief valve is opening only slightly is reduced.

In one embodiment the linear operating spring element(s) is pre-tensioned when the sealing element rests on said seat with a pre-tensioning force which
30 is at least about 5 % of total load, such as between about 10 % and about

90 %, such as between about 25 % and about 75 %, such between about 40% and about 60 %, such as between about 45 % and about 55 % of total load, e.g. about 50 % of total load.

5 The total load means the total force required to fully open the relief valve (the relief valve set point force). Such a set point force is sometimes called “crack open force” or “crack open pressure”.

10 In one embodiment the linear operating spring element(s) is pre-tensioned when the sealing element rests on said seat with a pre-tensioning force which is at least about 25 % of the load carried by said linear operating spring element(s), such as between about 40 % and about 98 %, such as between about 50% and about 90 %, such between about 60% and about 85 % of the load carried by said linear operating spring element(s).

15 The load carried by said linear operating spring element(s) means the force applied onto the specific spring element(s) when the total force required to open the relief valve fully is applied (the spring element set point force for said specific spring element(s)).

20 In one embodiment the linear operating spring element is pre-tensioned when the sealing element rests on the seat with a pre-tensioning force which is at least about 0.5 N, such as between about 1 and about 50 N, such as between about 1.5 and about 25 N, such between about 2 and about 10 N, such as between about 3 and about 7 N, e.g. about 4.5 N. The relief valve of this embodiment is for example useful as relief valve in an off-shore system e.g. a flexible pipe system.

25 The pre-tensioning force of the linear operating spring element(s) may preferably be adjustable. In one embodiment the set point of the relief valve is adjustable by adjusting the pre-tensioning force of the linear operating spring element(s). The linear operating spring element(s) may be pre-tensioned such that no further displacement of the sealing element with respect to the seat
30 will occur until a large percentage e.g. 90 % or more of the set point force of

the relief valve is applied, at which point a slightly extra added force (the remaining force to reach the set point) results in a displacement by which the relief valve will fully open due to action of the nonlinear spring element or the combined action of the spring elements in cooperation.

- 5 The nonlinear operating spring element may be any type of nonlinear operating spring element which can operate within the desired operation force interval, i.e. which is not operating essentially linear within the whole force interval from about 0 to about the spring element set point force for said specific nonlinear operating spring element.
- 10 In one embodiment the nonlinear operating spring element is operating essentially linear in a part of the force interval from about 0 to about the spring element set point force for said specific nonlinear operating spring element. For example the nonlinear operating spring element may operate essentially linear in a first part of the operation force interval e.g. the force interval from
- 15 about 0 to about x % of the spring element set point force for said specific nonlinear operating spring element, where x preferably may be in the interval up to about 95, such as in the interval from about 10 to about 90, such as in the interval from about 25 to about 85, such as in the interval from about 50 to about 80.
- 20 In one embodiment the nonlinear operating spring element comprises at least one of a leaf spring and a disc spring.

In one embodiment the nonlinear operating spring element is a snap-type spring element comprising a peak force value within the operation range of the relief valve.

- 25 The peak force value is preferably the set point force for said specific spring element.

In one embodiment the nonlinear operating spring element is a single disc spring or a series of stacked disc springs.

The force exerted by the nonlinear operating spring element as a (nonlinear) function of the displacement from equilibrium position, as well as the operation range of the spring element may have any desired value and should preferably be selected in dependence of the desired use of the relief valve, the desired set point of the relief valve as well as the desired spring element set point force for said specific spring element.

- The relief valve of the invention may in one embodiment comprise two or more nonlinear operating spring elements which nonlinear operating spring elements may be identical or they may be different from each other. In order not to have a mismatch of the nonlinear operation such nonlinear operating spring element in the same relief valve should preferably be selected in dependence of each other to have a similar nonlinear operational function. Preferably such nonlinear operating spring elements operating in the same relief valve are essentially identical. In one embodiment the relief valve comprises two or more, such 3, 4 or 8 preferably identical nonlinear operating spring elements. If one of the nonlinear operating spring elements in such a construction ceases to operate fully or partly, the relief valve may continue to operate with only a slight change of set point.
- In one embodiment of the relief valve the nonlinear operating spring element (or nonlinear operating spring elements if there are several) is pre-tensioned when the sealing element rests on the seat. It is generally known to pre-tension spring elements, and the skilled person will know how to establish and regulate such a pre-tensioning on the nonlinear operating spring element(s).
- The pre-tensioning of the nonlinear operating spring element(s) may add to providing a safe sealing between the seat and the sealing element when the relief valve is in its closed position. Furthermore the pre-tensioning of the nonlinear operating spring element(s) may result in a reduced or totally avoid a displacement of the sealing element relatively to the seat until the force applied to the pre-tensioned spring element has been overcome. Thereby the risk of a situation where the relief valve opens only slightly is reduced.

In one embodiment the nonlinear operating spring element(s) is pre-tensioned when the sealing element rests on said seat with a pre-tensioning force which is at least about 5 % of total load, such as between about 10 % and about 90 %, such as between about 25 % and about 75 %, such between about 40% and about 60 %, such as between about 45 % and about 55 % of total load, e.g. about 50 % of total load.

The total load means the total force required to fully open the relief valve total force (the relief valve set point force).

10 In one embodiment the nonlinear operating spring element(s) is pre-tensioned when the sealing element rests on said seat with a pre-tensioning force which is at least about 25 % of the load carried by said nonlinear operating spring element(s), such as between about 40 % and about 98 %, such as between about 50% and about 90 %, such between about 60% and about 85 % of the load carried by said nonlinear operating spring element(s).

The load carried by said nonlinear operating spring element(s) means the force applied onto the specific non linear spring element(s) when the total force required to fully open the relief valve is applied (the non linear spring element set point force for said specific nonlinear spring element(s)).

20 In one embodiment the nonlinear operating spring element is pre-tensioned when the sealing element rests on the seat with a pre-tensioning force which is at least about 0.5 N, such as between about 1 and about 50 N, such as between about 1.5 and about 25 N, such between about 2 and about 10 N, such as between about 3 and about 7 N, e.g. about 4.5 N. The relief valve of this embodiment is for example useful as relief valve in an off-shore system e.g. a flexible pipe system.

The pre-tensioning force of the nonlinear operating spring element(s) may preferably be adjustable. In one embodiment the set point of the relief valve is adjustable by adjusting the pre-tensioning force of the nonlinear operating spring element(s). The nonlinear operating spring element(s) may be pre-

tensioned such that no further displacement of the sealing element with respect to the seat will occur until a large percentage e.g. 90 % or more of the set point force of the relief valve is applied, at which point a slightly extra added force (the remaining force to reach the set point) results in a displacement by which the relief valve will fully open due to the combined action of the spring elements.

In one embodiment the relief valve comprises one or more pre-tensioned disc springs.

10 In one embodiment wherein the relief valve comprises at least one disc spring, said disc spring is pre-tensioned when said sealing element rests on said seat by being compressed to at least about 5 % of its compression range, such as between about 10 % and about 90 %, such as between about 25 % and about 75 %, such between about 40% and about 60 %, such as between
15 about 45 % and about 55 % of its compression range, wherein the disc spring compression range is determined as its difference in height in flat state and in unloaded state.

In one embodiment wherein the relief valve comprises at least one disc spring, said disc spring is pre-tensioned when said sealing element rests on said seat
20 with a pre-tensioning force which is at least about 0.5 N, such as between about 1 and about 50 N, such as between about 1.5 and about 25 N, such between about 2 and about 10 N, such as between about 3 and about 7 N, e.g. about 4 N.

In one embodiment the nonlinear operating spring element has a nonlinear
25 power curve with a peak power, said peak power being within the operation range of the relief valve.

In one embodiment the relief valve comprises at least one disc spring which is pre-tensioned when said sealing element rests on said seat with a pre-

tensioning force which is at least about 90 % of its peak force value, such as from about 95 % to about 98 % of its peak force value. Thereby the displacement of the disc spring from rest until immediately prior to its open state is relatively short.

- 5 In one embodiment the nonlinear operating spring comprises a peak force value within the operation range of the relief valve, the relief valve has a set point selected such that the force applied to the nonlinear operating spring element is about said peak force.

- 10 Preferably the nonlinear operating spring element has a nonlinear power curve within the operation range of the valve. The power curve is a function of the force (F_2) exerted by the nonlinear operating spring element and displacement (X_2) from equilibrium position.

- 15 In one embodiment the power curve is essentially linear when the force F_2 is up to about 50 % of the peak force, such as up to about 75 % of the peak force, such as up to about 90 % of the peak force, such as up to about 95 % of the peak force. When F_2 is outside the stated range, the power curve may preferably be highly nonlinear.

- 20 In one embodiment $\delta F_2 / \delta X_2$ of the nonlinear operating spring element when operating in the relief valve, is sufficiently small to essentially keep the relief valve in its closed position when F_2 is less than about 50 % of the peak force, such as less than about 75 % of the peak force, such as less than about 90 % of the peak force, such as less than about 95 % of the peak force.

- 25 The linear operating spring element(s) and the nonlinear operating spring element(s) of the relief valve should preferably be adjusted in relation to each other such that at least one linear operating spring element and at least one nonlinear operating spring element each carries a part of the total load (the force at the set point of the relief valve).

In one embodiment the linear operating spring element(s) is selected to and/or adjusted to carry at least about 20 % of the total load, such as between about 25 % and about 90 % of the total load, such as between about 40 % and about 80 % of the total load, such as between about 50 % and about 75 % of the total load in at least a part of, preferably in all of the operation range of the relief valve.

In one embodiment the linear operating spring element(s) is selected to and/or adjusted to carry from between about 1 to about 20 N, such as between about 1.5 and 10 N. The relief valve of this embodiment is for example useful as relief valve in an off shore system e.g. a flexible pipe system.

In one embodiment the linear operating spring element(s) is adjusted to carry all of the load, in at least a part of the operation range of the relief valve, preferably the linear operating spring element is adjusted to carry all of the load in a part of the operation range comprising the range from open position to closed position.

In one embodiment the linear operating spring element is arranged to carry up to about 90 % of the relief valve set point force, such as between about 25 % and about 90 % of the relief valve set point force, such as between about 40 % and about 80 % of the relief valve set point force, such as between about 50 % and about 75 % of the relief valve set point force.

In one embodiment the linear operating spring element is arranged to carry from about 6 N to about 10 N of the relief valve set point force, such as from about 7 N to about 9 N of the relief valve set point force, such as from about 7.5 to about 8.1 N of the relief valve set point force. The relief valve of this embodiment is for example useful as relief valve in an off-shore system e.g. a flexible pipe system.

Each of the spring elements each has a force curve which is force carried by the respective spring element relative to displacement of said respective spring element. The linear operating spring element has an essentially linear

force curve in the operation range of the relief valve and the nonlinear operating spring element has a nonlinear force curve in the operation range of the relief valve.

In one embodiment nonlinear operating spring element(s) has a force curve when the relief valve is in its open position, said linear operating spring element(s) has a positive force curve which force curve is preferably higher in force value than said negative force curve of said nonlinear operating spring element when the relief valve is in its open position. Thereby the linear operating spring element(s) may provide a full closure of the relief valve when the pressure on the high pressure side has been reduced to a selected level.

In one embodiment the linear operating spring element(s) when the relief valve is in its open position carries a force which is at least the relief valve closing set point force. The relief valve closing set point force preferably being about the valve displacement multiplied with the spring constant ($K1 * X1$) minus reduction in force carried by the nonlinear operating spring element(s) from set point to said open position (ΔF).

The relief valve closing set point value is preferably a selected value which is at least $K1 * X1_{open}$ for the linear operating spring element, where $X1_{open}$ is the displacement of the linear operating spring element when the relief valve is in its open position. The relief valve closing set point value is preferably selected to be in the interval from about $0.9 * (K1 * X1_{open} - \Delta F)$ to about $(K1 * X1_{open} - 0.9 * \Delta F)$.

The relief valve closing set point force preferably being from about 70 % to about 99 % of the relief valve set point force, such as from about 75 to about 95 % of the relief valve set point force, such as from about 80 % to about 90 % of the relief valve set point force.

In one embodiment the linear operating spring element is composed of two or more cooperating sub-elements, such as two or more compression springs.

In one embodiment the relief valve comprises two or more linear operating spring elements.

In one embodiment the relief valve has a relief valve set point force and said spring elements are arranged such that said relief valve remains in its closed position until the force applied at the inlet side reaches said set point force, at which point the nonlinear operating spring element snap-opens and the force
5 carried by the nonlinear operating spring element simultaneously decreases ΔF . The relief valve is now open and allows a passage of fluid and thereby allowing the force applied at the inlet side to drop to a relief valve closing set point force value, at which relief valve closing set point force value, $K_1 \cdot X_1$ for said linear operating spring element increases the sum of ΔF and the force
10 applied at the inlet side and the nonlinear operating spring element will snap-close.

As mentioned above the relief valve of the invention has an unlimited number of applications. In practice it can replace any prior art relief valves, in particular gas pressure relief valves but also other fluid pressure relief valves.

15 The selected operating range of the spring elements and the set points of the relief valves as well as the specific design and size of the relief valve should preferably be selected in accordance with the desired use of the relief valve.

In a preferred embodiment the relief valve is adapted for use in an offshore system, such as for gas relief in an offshore pipe. Such offshore systems are
20 e.g. disclosed in for example US 6,152,170 US 6,065,501, US 5,813,439 and WO 01/81809 as well as in "Recommended Practice for Flexible Pipe API 17B, Mar 1, 2002" and "Specification for Unbounded Flexible Pipe 17J, Nov 1, 1999" or any updated versions thereof.

The invention therefore relates to a use of the relief valve in an offshore
25 system such as for gas pressure relief in an offshore pipe e.g. a flexible offshore pipe.

The invention also relates to a method of relieving the pressure in an annulus of an offshore pipe comprising applying a relief valve as claimed in any one of the preceding claims so that the inlet side of the relief valve is in fluid
30 communication with an annulus of the offshore pipe.

In one embodiment the relief valve is placed in an end-fitting of the offshore system.

Such end fitting in an offshore system is generally known in the art. Examples of end fittings can be found in WO04085905, US6412825 and US6923477.

5 BRIEF DESCRIPTION OF DRAWINGS

The invention will be explained more fully below in connection with a preferred embodiment and with reference to the drawings in which:

FIG. 1 is a schematic side view of a relief valve of the invention.

FIG. 2 is a power curve of a nonlinear operating spring element of a relief
10 valve of the invention.

The relief valve shown in FIG. 1 comprises a house 8, with a lid 8' fixed to each other with the bolt 10. The house 8 comprises an inlet side indicated by the arrow 7 and an outlet side 1. The relief valve further comprises a seat 3 and a sealing element 2 displaceable with respect to each other. The sealing
15 element 2 comprises a gasket 2' arranged to seal against the seat 3. The sealing element 2 is a sealing disk member and the seat 3 is an annular seat member. The sealing disk member 2 is connected to a valve rod 9 (also called a poppet).

The relief valve further comprises a first and a second spring element 4, 6, the
20 sealing element 2 is displaced with respect to said seat 3 to provide passage from the inlet side 7 to said outlet side 1 when the relief valve is in its open position. The first and said second spring element 4, 6 are arranged to apply a closing pressure when the relief valve is in its closed position. The first
25 spring element 4 is a linear operating spring element and said second spring element 6 is a nonlinear operating spring element. In the shown embodiment the linear operating spring element is a spiral spring 4 and the nonlinear operating spring element is a disk spring 6. The relief valve shown I FIG. 1 may comprise 2 or more spiral springs in replacement of the shown spiral

spring 4. Such 2 or more spiral spring may e.g. be arranged concentrically to each other.

Additionally the relief valve could comprise 2 or more identical disk springs preferably arranged parallel to each other e.g. by stacking, in side by side
5 relationship or concentrically inside each other.

The spring element acts indirectly on the sealing disk member via an additional valve element 5 shaped as an annular ring which is in engagement with the valve rod 9.

In the shown embodiment the seat 3 is fixed and the sealing element 2 is
10 movable.

FIG. 2 shows an example of a power curve of a nonlinear operating spring element of a relief valve of the invention. This power curve could be the power-curve for the disk spring 6 shown in FIG. 1.

The relief valve of the invention shown in FIG. 2 is designed to prevent
15 continuous leak at low flow-rate. Once the relief valve has reached its set point the relief valve will fully open and it will stay essentially fully opened until a relief valve closing set point value has been reached and it shuts again with a snap.

This actuation is achieved by using a combination of the spiral spring 4 and of
20 the disc spring 6.

The spiral spring 4 may e.g. be chosen to carry at 20 - 80 % of the load. At the same time it may be designed to a relatively low spring-rate so that additional compression does not counterbalance the actuation of the spring-disc.

25 The disc spring 6 may be pre-tensioned to just below peak force of its power-curve. Any additional force applied will take it beyond the peak force where its spring-rate turns negative with increase of lift.

Only at this stage the relief valve will allow fluid to flow. Creeping leakage of tiny bubbles and similar is prevented; overpressure may be evacuated in one big bubble, washing debris away from the outlet area 1.

- 5 When pressure at the inlet side has fallen below the relief valve closing set point value then the sealing element 2 moves back to the seat 3. With the reduction of lift force of the disc spring 6 helps closing the relief valve. Small leakage (bubbles) which is typical of the prior art relief valve with slow-reseat solutions is prevented.
- 10 The additional valve element 5 shaped as an annular ring forms a flange which ensures that the snapped disc spring 6 is caught and turned back into normal position. The spiral spring 4 ensures a driving force to close the valve at all stages.

- Further scope of applicability of the present invention will become apparent from the detailed description given hereinafter. However, it should be understood that the detailed description and specific examples, while indicating preferred embodiments of the invention, are given by way of illustration only, since various changes and modifications within the spirit and scope of the invention will become apparent to those skilled in the art from this detailed description.
- 15
- 20

The figures are schematic and simplified for clarity, and they just show details which are essential to the understanding of the invention, while other details are left out. Throughout, the same reference numerals are used for identical or corresponding parts.

- 25 Some preferred embodiments have been shown in the foregoing, but it should be stressed that the invention is not limited to these, but may be embodied in other ways within the subject-matter defined in the following claims.

CLAIMS

1. A relief valve comprising a house with an inlet side and an outlet side, a seat and a sealing element displaceable with respect to each other, and a first and a second spring element, said relief valve having a closed position and an open position, said sealing element rests on said seat when the relief valve is in its closed position and said sealing element is displaced with respect to said seat to provide passage from said inlet side to said outlet side when said relief valve is in its open position; said first and said second spring element are arranged to apply a closing pressure when the relief valve is in its closed position, wherein said first spring element is a linear operating spring element and said second spring element is a nonlinear operating spring element, the nonlinear operating spring comprises a peak force value within an operation range of the relief valve

2. A relief valve as claimed in claim 1 wherein the linear operating spring element is a compression spring, preferably a coiled spring, such as a helical spring.

3. A relief valve as claimed in any one of claims 1 and 2 wherein the linear operating spring element is following Hookes law ($F1 = -K1 \cdot X1$) in its operation range, wherein

$F1$ = Force (N) exerted by the spring element,

$K1$ = Spring Constant (N/mm),

$X1$ = Displacement (mm) from equilibrium position.

4. A relief valve as claimed in claim 3 wherein the spring constant ($K1$) is up to about 30 N/mm, such as from about 0.5 to about 25 N/mm, such as from about 0.8 to about 10 N/mm, such as from about 1 to about 3 N/mm, e.g. about 1.3 N/mm.

5. A relief valve as claimed in any one of the preceding claims wherein the linear operating spring element is pre-tensioned when said sealing element rests on said seat, preferably said linear operating spring element is pre-tensioned when said sealing element rests on said seat with a pre-tensioning force which is at least about 5 % of total load, such as between about 10 % and about 90 %, such as between about 25 % and about 75 %, such between about 40% and about 60 %, such as between about 45 % and about 55 % of total load, e.g. about 50 % of total load.
6. A relief valve as claimed in claim 5, wherein said linear operating spring element is pre-tensioned when said sealing element rests on said seat with a pre-tensioning force which is at least about 0.5 N, such as between about 1 and about 50 N, such as between about 1.5 and about 25 N, such between about 2 and about 10 N, such as between about 3 and about 7 N, e.g. about 4.5 N.
7. A relief valve as claimed in any one of claims 5 and 6, wherein said pre-tensioning force of said linear operating spring element is adjustable.
8. A relief valve as claimed in any one of the preceding claims wherein said nonlinear operating spring element comprises at least one of a leaf spring and a disc spring.
9. A relief valve as claimed in any one of the preceding claims wherein said nonlinear operating spring element is a snap-type spring element comprising a peak force value within the operation range of the relief valve.
10. A relief valve as claimed in one of the preceding claims wherein said nonlinear operating spring element is a single disc spring or a series of stacked disc springs.
11. A relief valve as claimed in any one of claims 8-10 wherein at least one disc spring is pre-tensioned when said sealing element rests on said seat by being compressed to at least about 5 % of its compression range, such as between about 10 % and about 90 %, such as between about 25 % and about

75 %, such between about 40% and about 60 %, such as between about 45 % and about 55 % of its compression range, wherein the disc spring compression range is determined as its difference in height in flat state and in unloaded state.

12. A relief valve as claimed in any one of claims 8-11 wherein at least one disc spring is pre-tensioned when said sealing element rests on said seat with a pre-tensioning force which is at least about 0.5 N, such as between about 1 and about 50 N, such as between about 1.5 and about 25 N, such between about 2 and about 10 N, such as between about 3 and about 7 N, e.g. about 4 N.

13. A relief valve as claimed in any one of claims 8-12 wherein at least one disc spring is pre-tensioned when said sealing element rests on said seat with a pre-tensioning force which is at least about 90 % of its peak force value, such as from about 95 % to about 98 % of its peak force value.

14. A relief valve as claimed in any one of the preceding claims wherein said nonlinear operating spring element has a nonlinear power curve with a peak power, said peak power being within the operation range of the relief valve.

15. A relief valve as claimed in any one of the preceding claims wherein said first and said second spring element independently of each other apply a closing pressure when the relief valve is in its closed position, the nonlinear operating spring preferably comprises a peak force value within the operation range of the relief valve, the relief valve has a set point selected such that the force applied to the nonlinear operating spring element is about said peak force.

16. A relief valve as claimed in any one of the preceding claims wherein said nonlinear operating spring element has a nonlinear power curve within the operation range of the valve, the power curve being a function of the force (F2) exerted by the nonlinear operating spring element and displacement (X2) from equilibrium position.

17. A relief valve as claimed in claim 16 wherein $\delta F_2/\delta X_2$ of the nonlinear operating spring element when operating in the relief valve, is sufficiently small to essentially keep the relief valve in its closed position when F_2 is less than about 50 % of the peak force, such as less than about 75 % of the peak force, such as less than about 90 % of the peak force, such as less than about 95 % of the peak force.

18. A relief valve as claimed in any one of the preceding claims wherein the linear operating spring element is adjusted to carry at least about 20 % of the total load, such as between about 25 % and about 90 % of the total load, such as between about 40 % and about 80 % of the total load, such as between about 50 % and about 75 % of the total load in at least a part of, preferably in all of the operation range of the relief valve.

19. A relief valve as claimed in any one of the preceding claims wherein the linear operating spring element is adjusted to carry from between about 1 to about 20 N, such as between about 1.5 and 10 N.

20. A relief valve as claimed in any one of the preceding claims wherein the linear operating spring element is adjusted to carry all of the load, in at least a part of the operation range of the relief valve, preferably the linear operating spring element is adjusted to carry all of the load in a part of the operation range comprising the range from open position to closed position.

21. A relief valve as claimed in any one of the preceding claims wherein the linear operating spring element is arranged to carry up to about 90 % of the relief valve set point force, such as between about 25 % and about 90 % of the relief valve set point force, such as between about 40 % and about 80 % of the relief valve set point force, such as between about 50 % and about 75 % of the relief valve set point force.

22. A relief valve as claimed in any one of the preceding claims wherein the spring elements each has a force curve, the nonlinear operating spring element has a negative force curve when the relief valve is in its open position, said linear operating spring element has a positive force curve which

preferably has a higher F value larger than said negative force curve of said nonlinear operating spring element when the relief valve is in its open position.

23. A relief valve as claimed in any one of the preceding claims wherein the linear operating spring element when the relief valve is in its open position carries a force which is at least the relief valve closing set point force, said relief valve closing set point force preferably being about the valve displacement multiplied with the spring constant ($K1 * X1$) minus reduction in force carried by the nonlinear operating spring element from set point to said open position (ΔF), said relief valve closing set point force preferably being from about 70 % to about 99 % of the relief valve set point force, such as from about 75 to about 95 % of the relief valve set point force, such as from about 80 % to about 90 % of the relief valve set point force.

24. A relief valve as claimed in any one of the preceding claims wherein the linear operating spring element is composed of two or more cooperating sub-elements, such as two or more compression springs.

25. A relief valve as claimed in any one of the preceding claims wherein the relief valve comprises two or more linear operating spring elements.

26. A relief valve as claimed in any one of the preceding claims wherein the linear operating spring element is connected to one of said sealing element and said seat in a non-elastic connection.

27. A relief valve as claimed in any one of the preceding claims 1-25 wherein the linear operating spring element is connected to at least one of said sealing element and said seat in an elastic connection, the elastic connection preferably being provided by a secondary linear spring with a K value (spring constant) higher than the value of the linear operating spring element.

28. A relief valve as claimed in any one of the preceding claims wherein the relief valve has a set point force which is the force which will move the relief valve from its closed position to its open position when applied at the

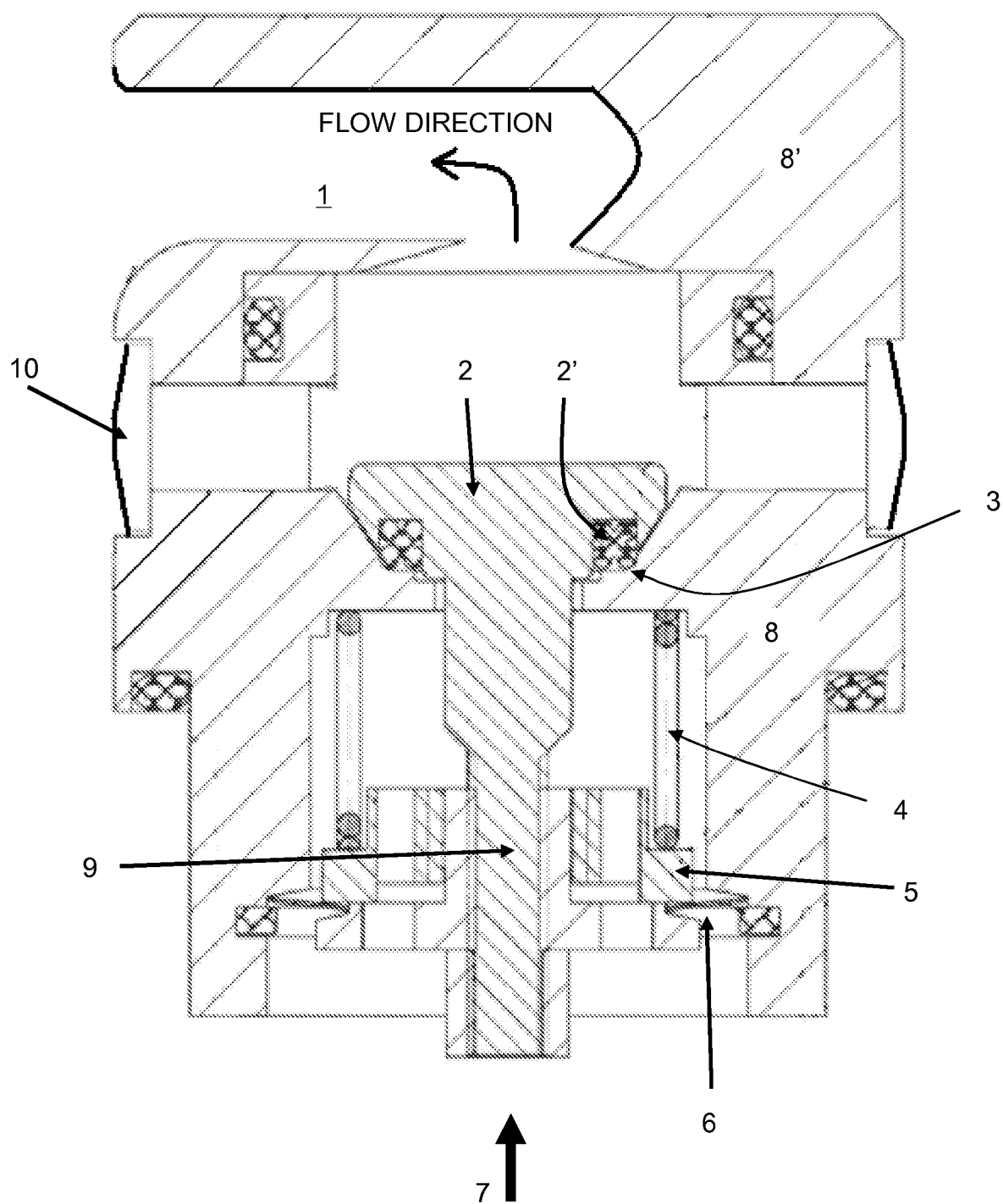
inlet side, said spring elements are arranged such that said relief valve remains in its closed position until the force applied at the inlet side reaches said set point force, at which point the nonlinear operating spring element snap-opens, the force carried by the nonlinear operating spring element decreases ΔF , and allowing the force applied at the inlet side to drop to a relief valve closing set point force value, at which relief valve closing set point force value $K1 * X1$ for the linear operating spring element increases the sum of ΔF and the force applied at the inlet side and the nonlinear operating spring element will snap-close.

29. Use of a relief valve as claimed in any one of the preceding claims in an offshore system, such as for gas relief in an off shore pipe.

30. A method of relieving the pressure in an annulus of an offshore pipe comprising applying a relief valve as claimed in any one of the preceding claims so that the inlet side of the relief valve is in fluid communication with the annulus.

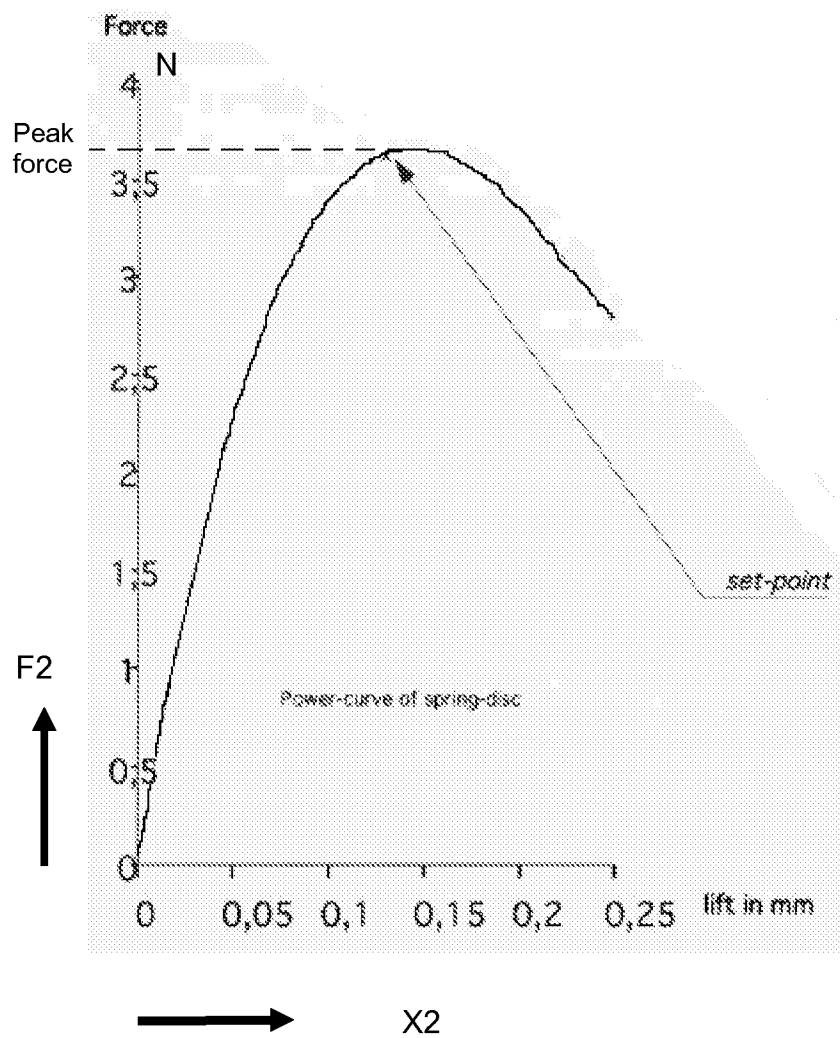
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Fig. 1



2/2

Fig. 2



INTERNATIONAL SEARCH REPORT

International application No.

PCT/DK2010/050038

A. CLASSIFICATION OF SUBJECT MATTER
F16K17/04 (2006.01)

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
ECLA, IPC: F16K

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

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US2004060600 A1 (CHOATE, JEREMY R. et al.) 01.04.2004 see abstract, figures and section 0102	1-14
X	US3762434 A (ALLEN T. et al.) 02.10.1973 see abstract, figures and column 2 line 13 - line 47	1-5
A	US2557536 A (DRANE, PHILIPS B. et al.) 19.06.1951	-

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

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

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Date of the actual completion of the international search

09/04/2010

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INTERNATIONAL SEARCH REPORT.

International application No.

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