

METHOD AND ARRANGEMENT FOR MAINTAINING FLUID FLOW PRESSURE IN A SYSTEM AT A PRESET, ALMOST CONSTANT LEVEL

This invention relates to a method according to the preamble of the claim 1 for maintaining fluid flow pressure in a system at a preset, almost constant level, not depending on periodical variation of the mass flow pumped into it.

The invention relates also to an arrangement applying the method, typical features of which are defined in the preamble of the claim 5.

A nozzle valve, as a part of the arrangement which applies the invention, converts the flow into a high pressure jet, which is directed to impulse turbine buckets. The invention is especially suitable for use with wave power and reverse osmosis systems.

Publication WO 2004099658 A1 relates to a turbine nozzle valve, opening of which is regulated by an electric gear motor and its quick closure is achieved by use of a pressure accumulator.

Publications US 58322944 and WO 9813633 A1 relate to a turbine nozzle valve, opening of which is regulated with an electric gear motor. In the latter quick closure of the valve is carried out by use of a pressure accumulator.

It is well known that water can be pumped by use of wave power. The pumped mass flow varies occasionally, depending on the wind conditions. In contrast to the conventional water power plants, water which is pumped with wave power does not have potential energy and the resulting constant pressure. For this reason the flow pressure must be specifically arranged. A typical solution is a throttle valve installed at the system's outflow, causing pressure rise. Such a valve can be an impulse turbine nozzle valve, which at the same directs a jet to the turbine buckets. Fig.1a.

An earlier known nozzle valve, which resembles the invention and is used with a Pelton turbine, is described in the figures Fig.2a and Fig.2b. This kind of valves are used when the flow pressure derives from the height difference between water levels, in which case hydrostatic pressure remains constant and does not depend on the amount of mass flow streaming through the nozzle. Cross-sectional area of the nozzle mouth can be adjusted by moving a conical needle in

it and due to this the mass flow through it varies, but the jet speed remains unchanged due to the constant pressure. Speed of the jet is:

$v = C_v \cdot \sqrt{2gH}$, where H (head) is height of the water penstock (m), C_v is nozzle coefficient $\approx 0,98$. This equation means that the jet's velocity depends only on the pressure, which on its behalf depends on the penstock height.

In small power plants the needle is usually adjusted with hand operated mechanisms, Fig.2a, and in the bigger, over 100kW systems, by governor mechanisms, in which the needle movement is achieved with servo motor pressurized oil, Fig.2b. The purpose of these mechanisms is to regulate the mass flow into the nozzle so that the flow corresponds the turbine load. Kinetic energy of the jet $E_v = (mv^2)/2$ is varying according to the mass flow variations and the turbine power will change accordingly. So the jet velocity depends only on the pressure caused by the water head.

It is obvious that it does not make sense to produce energy with water, which has been pressurized with electric or diesel pumps. This is why the valves mentioned above have been intended to operate with turbines in the power plants, where water has potential energy. They are not intended and not suitable when the nozzle valve itself must maintain the pressure constant in a system, into which pumped mass flow is occasionally varying.

In contrast to these, operating principle of the nozzle valve according to the invention just is to independently maintain the system pressure constant not depending on the mass flow variations. As a preferred use of it is to utilize the amount of energy, which the water which is pumped by wave energy and also the reverse osmosis reject contain.

The jet velocity remains constant if water pressure remains constant. For example 50bar pressure in the equation above corresponds a 500 meter high water penstock.

Because the jet speed depends only on the pressure, so when the pressure remains constant the turbine power $P_{max} = \dot{m} \cdot p$, where $\dot{m}$ is the mass flow and p pressure, changes in direct proportion to the mass flow change. It is clear that if both the mass flow and pressure simultaneously drop, as the case is with a constant mouth nozzle, then the power drops drastically.

Simultaneous variation of the flow volume and pressure is problematic also as to the operation of a reverse osmosis system, because the salt-water pressure in the reverse osmosis modules must be higher than the osmotic pressure of the water, which in case of sea water is over 36bar. So the constant throttling commonly used in these systems, is only applicable when the pumped inflow is constant. However, with wave energy that never is the case. In a reverse osmosis system the throttling device is installed on the reject tube. Reject is the salt concentrate, which outflows from the module and the flow throttling nozzle forms a jet, directing it to the turbine, Fig.1b.

Reject, which is outflowing from the reverse osmosis module, can contain 70-90% of the initial pumping energy.

The device which throttles and maintains the reverse osmosis flow pressure can for example be a pressure relief valve. Then however an essential problem is that after the throttle the energy which the reject has contained is lost and cannot be utilized in the turbine. Opening pressure in a mechanically operating pressure relief valve is about double to its closing pressure, which creates a problem in reverse osmosis systems.

For the reasons described above, it is essential that pressure in the flow throttling valve remains constant also in cases when the inflow is occasionally varying.

The purpose of the invention is to create a method and arrangement in which a nozzle valve maintains fluid flow pressure in a system at a preset level and almost constant, not depending on periodical variations of the mass flow pumped into it. The same nozzle valve converts the flow into a high pressure jet directing it for example to impulse turbine buckets.

This purpose is achieved with the method according to the invention characterized in the claim 1 and with the arrangement according to the invention characterized the claim 5.

The invention is especially suitable to be used for maintaining reverse osmosis system pressure and utilizing its reject pressure by use of a Pelton turbine. Then the sweet water production and by the reject force operating impulse turbine will have optimal efficiency.

The method and arrangement according to the invention are more detailed described in the following with reference to the figures Fig.1a, Fig.3a, and Fig.3b.

The nozzle valve 1 comprises a hollow and long, preferably cylindrical body 2, which can be assembled of several parts and at the other end of which, in direction of the body 2 axis is a nozzle channel 8, which is preferably conical, having circular cross-section and through which the outflow is arranged. Inflow into the body 2 happens through a channel 3 in the body wall.

For sake of clarity that end of the body 2 where the channel 8 is situated is referred hereinafter to the lower part of the body 2.

The channel 8 is opened and closed with a reciprocating movement of the needle 4 inside the body 2. The needle is formed of an essentially cylindrical shaft and conical head, which opens and closes gradually the channel 8 by changing its cross-sectional flow area when moving in it.

When the channel 8 is closed, the needle 4 head has a small clearance to the channel 8 mouth. When the channel 8 is closed it does not have to be totally sealant, it is enough that the flow through it is essentially blocked. The upper end of the body 2, which is opposite to the channel 8, has a pressure accumulator 6 joined to it, directly or with an intermediate tube 14, in such a way that the inflow into the block 2 can also get beneath the valve disc 10 of the accumulator 6 through the channel 9, which is formed between the body 2 and accumulator 6 and the needle 4 can move in the channel 9 axially reciprocating. A slide element 11 is mounted inside the body 2 to guide the needle 4 shaft. Outside the slide element 11 there are grooves or channels 13 in the body 2 wall through which into the body 2 through the channel 3 inflowing stream can pass to the other side of the slide element 11 and proceed to the channel 9 and consequently beneath the valve disc 10, which closes the pre-pressurized accumulator 6. Fig.3b. It is also possible that the groove or channel 13 is in the needle 4 shaft.

At the beginning, when there is no flow, the needle 4 head closes the channel 8 and the needle 4 is then at its lowest position and the disc 10 is supported by the accumulator 6 body. Fig.3a. In this situation the needle 4 shaft end is pressed against the disc 10 by means of a compression spring 5. The spring 5 is tensioned and has its lower end essentially supported by the slide element 11 or

the body 2 and its upper end by a plate 12 mounted on the needle 4 shaft or by a widening at the shaft.

When a hydraulic pump begins to pump inflow into the system, the flow pressure rises in the body 2 because the flow is not able to go out through the channel 8 while the needle 4 is closing it. Neither can the needle 4 move because its upper end, by means of the spring 5, is compressed against the valve disc 10, which closes the accumulator 6. For this reason the flow pressure increases until it exceeds into the accumulator 6 pre-pressurized pressure p_0 and then the disc 10 begins to rise because of the lifting force affecting it. This lifting force is sum of the spring force F_s and the force which the flow pressure p_1 causes on the needle 4. The spring force holds the needle 4 shaft end all the time essentially touching the disc 10. Because the pressure p_1 is high, it is possible that it can enter between the needle shaft end and the disc 10. In that case the pressure p_1 would try to press the needle downwards and because of this the spring force must in all situations be greater than this downwards pressing force.

As the conical needle 4 head rises with the disc 10, the outflow channel 8 opens and its cross-sectional flow area correspondingly increases. Fig.3b. Channel 8 opens just that much that the flow volume through it corresponds the pressure p_2 . Gas pressure p_2 in the diaphragm pressure accumulator 6 and the inflow pressure p_1 in the valve 1 are essentially equal in all operational flow situations.

The greater gas volume the accumulator 6 has, the smaller is the difference between p_2 and into the accumulator 6 pre-pressurized pressure p_0 . This is because then the relative gas volume change in the accumulator 6, due to the needle 4 rise, remains minor. The maximum operational volume change should be less than 16%, advantageously less than 9% of the accumulator's volume at the point of reaching operational pressure level of the accumulator.

Ratio of maximum operating pressure p_2 to gas pre-charge pressure p_0 can never be higher than accumulator's design pressure ratio given by manufacturer, normally 4:1

Pressure rise from p_0 to p_2 in the accumulator (6) is inversely proportional to its gas volume change due to the needle (4) rise. The maximal operational pressure p_2 can be chosen to desired level by selection of p_0 , accumulator volume, cone

angle of the needle (4) head and cross-section of the channel (8) mouth according to the maximal operational flow volume.

Advantageous operational pressure ratio due to the needle (4) rise: $p_2/p_0 < 1.1$.

This way the flow pressure p_1 remains almost constant even though the flow volume occasionally varies, and as a result of this also pressure in the whole system remains essentially constant. When the inflow ceases, the valve 1 maintains the system pressure at level p_0 . However it is beneficial to a reverse osmosis module that no highly concentrated salt water stays in it and so the channel 8 can be left slightly open. When used with a reverse osmosis system the initial pressure p_0 in the accumulator 6 is chosen higher than osmotic pressure of the saline water to be treated. Pressure p_0 is set essentially to the level at which the operational pressure in the whole system is desired be and at which the jet, provided by the valve 1, begins.

The spring 5 force is defined according to the circular cross-section area of the outflow channel 8 mouth, pre-pressurized initial gas pressure p_0 in the accumulator 6 and the maximal operational movement of the needle 4. The spring force F_s must be the greater one in following equations:

- a) $F_s = p_2 \cdot A_7$, when needle 4 is at its highest operational position
- b) $F_s = p_0 \cdot A_7$, when needle 4 is closing the channel 8.

A_7 is the cross-sectional area of the conical needle 4 head just at the channel 8 mouth, perpendicular to its longitudinal axis at the current operational moment. Because in practice the flow pressure p_1 can enter between the needle 4 shaft end and the valve disc 10, so in order the needle 4 to rise with the valve disc 10, the spring force lifting the needle 4 must be greater than the force caused by pressure p_1 which is pressing it downwards.

However the needed spring force is relatively small and only a fraction compared to the spring forces of the conventional pressure relief valves. In the solution according to the invention the needle 4 movement is smooth and frictionless and it moves quickly as a result of even the smallest change attempt of the pressure p_1 , thus maintaining it essentially constant.

The needle (4) moves according to the inflow changes because as the cross-sectional area of the channel 8 mouth stays constant, flow pressure p_1 in the

valve rises or drops. According to the invention, gas pressure p_2 in the accumulator 6 begins to push the valve disc 10 and due to this the needle 4 downwards immediately when flow pressure p_1 gets below the gas pressure p_2 and correspondingly flow pressure p_1 begins to lift the disc 10 and due to this needle 4 immediately when it exceeds the gas pressure p_2 . As a result of this movement, clearance between the conical needle 4 head and channel 8 mouth changes as a function of the flow volume change and due to this the flow pressure remains essentially constant.

In this way system pressure and due to this velocity of the jet through the nozzle channel 8 remains essentially constant. When the flow stops the channel 8 gets closed because the pressure in the accumulator 6 pushes the disc 10 and the conical needle 4 head into their lowest position. The needle 4 head does not get stuck in the channel 8 because the disc 10 movement stops against the accumulator 6 body, causing also the needle 4 movement to stop.

An alternative arrangement in which the upper end of the needle 4 shaft is fixed to the valve disc 10, is also possible. In that case the spring 5 is not obligatory, even though advantageous. This kind of arrangement requires a special pressure accumulator, which so far are not in the market.

It is also possible that instead of the diaphragm accumulator 6, a bladder accumulator is utilized. However, as to the structure and operation, this would in practice be less favorable than a diaphragm accumulator.

The inflow volume could increase higher than designed for the system, for example during storm conditions, and due to this the system pressure would exceed its design value. This excessive flow and pressure rise can be avoided by use of another valve which operate with the same principle and is installed in the system before the valve 1 and is adjusted to open with a slightly higher pressure than the designed maxim pressure p_2 .

Claims

1. A method for maintaining fluid flow pressure in a system at a preset, almost constant level, not depending on periodical variation of the mass flow pumped into it, which system comprises at least one pressure accumulator (6) and a nozzle valve (1), which has a valve body (2) and axially inside it a conical needle (4) for opening and closing the mouth of its outflow channel (8), and the needle (4) shaft is guided by a slide element (11) mounted inside the valve body (2) and inflow into the valve body (2) can pass to the other side of the slide element (11) through one or several channels (13) and the needle (4) is moved axially to directions for opening and closing the valve (1) by means of the forces which are affecting on it and thus it adjusts the cross-sectional area of the outflow channel (8) mouth, **characterized** by the steps of exerting a force on the needle (4) shaft by the flow pressure (p_1) and a spring (5) together, the direction of this combined net force is upward in all situations and the combined net force holds the needle (4) shaft end constantly pressed against the pressure accumulator's valve disc (10) tending to open it, but is always smaller than the opposite force which in the accumulator (6) pre-pressurized gas pressure (p_0) exerts on the valve disc (10), that the mentioned combined net force in combination with the force, which the flow pressure (p_1) is exerting on the valve disc (10) form the first force which tends to open the outflow channel (8) against the second and opposite force, which the accumulator's (6) gas pressure is exerting on the valve disc (10), whereby, when the first force exceeds the second force, begin both the valve disk (10) and the needle (4) which is pressed against it, together, to rise, with the result that pressure (p_2) in the accumulator (6) increases accordingly, and choosing the diameter of the outflow channel (8) mouth, cone angle of the needle (4) and volume of the pressure accumulator (6) so that the gas volume change in the accumulator (6) caused by the needle (4) rise and the resulting increase in the accumulator's pressure is small also with maximal flow, with the result that the relationship between the mentioned forces automatically adjusts the opening grade of the valve so that the fluid flow pressure (p_1) remains close to the initial pressure (p_0) pre-pressurized in the accumulator (6), while the fluid flow through the outflow channel (8) remains all the time continuous.

2. Method according to the claim 1, **characterized** by that the spring force F_s , which is lifting the needle (4) and pressing its shaft end against the valve disc

(10), is equal or higher than greater of the forces defined in the following equations a and b:

a) $F_s = p_2 \cdot A_7$ when the needle (4) is at the highest operational position, defined by the system's maximal design pressure

b) $F_s = p_0 \cdot A_7$ when the needle (4) closes the outlet channel (8); and in these equations A_7 is cross-sectional area of the needle (4) head, perpendicular to its axis at the channel (8) mouth at the actual operational situation.

3. Method according to the claims 1 and 2, **characterized** in that the pressure accumulator (6) is a diaphragm or bladder accumulator and the inner side of the diaphragm is affected by the initial pressure (p_0) in the accumulator (6) and the outer side of the diaphragm is affected by the fluid flow pressure (p_1) and by this means the diaphragm and the needle (4) fixed into it move as a result of the changes in the flow pressure and at the same minimizing these changes.

4. Method according to the claims 1 - 3, **characterized** in that when the nozzle valve (1) is used for maintaining pressure in a reverse osmosis system, the initial pressure (p_0) in the accumulator (6) is chosen higher than the osmotic pressure of the saline water to be treated.

5. Arrangement for maintaining fluid flow pressure in a system at a preset, almost constant level, not depending on periodical variation of the mass flow pumped into it, which system comprises at least one pressure accumulator (6) and a nozzle valve (1), which has a valve body (2) and axially inside it a conical needle (4) for opening and closing the mouth of its outflow channel (8), and the shaft of the needle (4) is guided by a slide element (11) mounted inside the valve body (2) and the inflow into the valve body (2) can pass to the other side of the slide element through one or several channels (13), and the needle (4) is arranged to be moveable upwards to the opening direction of the valve and downwards by means of the forces affecting the needle (4), in order to adjust the cross-sectional area of the outflow channel (8) mouth, **characterized** in that to the upper end of the valve body (2), opposite the outflow channel (8), is joined a diaphragm or bladder accumulator (6) having a pre-pressurized initial gas pressure (p_0), and between the valve body (2) and the accumulator (6) is formed a channel (9) through which the needle (4) shaft end is arranged to be essentially pressured against the valve disc (10) of the accumulator (6) and to

move together with it, the initial pressure (p_0) causing a downward force tending to close the valve (1), that when the valve disc (10) is at its lowest position and supported by the accumulator (6) body, the conical head of the needle (4) essentially closes the mouth of the outflow channel (8), and into the system pumped mass flow is adapted to cause on the valve disc (10) and needle (4) forces, which tend to open the valve, and a pre-tensioned spring (5) is arranged to cause on the needle (4) a spring force (F_s) which tries to lift the needle and this spring force combined with the mass flow forces tends to rise the valve disc (10) and the needle (4) against the force, which the initial pressure (p_0) in the accumulator (6) causes on the valve disc (10), in order to open the outflow channel (8) and at the same time increase pressure in the accumulator (6) to the level (p_2) which corresponds the rise of the needle (4), and that diameter of the outflow channel (8) mouth, cone angle of the needle (4) and gas volume in the accumulator are so chosen that the gas volume change in the accumulator (6) caused by the needle (4) rise and the resulting pressure increase in the accumulator is small also with maximal flow volume, resulting that the pressure accumulator (6) adjusts the cross-sectional area of the outflow channel (8) mouth so that the flow pressure (p_1) of the fluid which will flow out and by this means pressure in the whole system remains close to the pre-pressurized initial pressure (p_0) in the accumulator (6).

6. Arrangement according to the claim 5, **characterized** by that the pre-tensioned spring (5) is a compression spring one end of which is supported by the valve body (2) or the slide element (11) and the other end by a widening (12), which is made or mounted on the needle (4) shaft, resulting that the spring force (F_s) which tends to lift the needle (4) is summed with the force which the flow pressure (p_1) causes on the needle.

7. Arrangement according to the claim 6, **characterized** by that the spring force F_s , which is lifting the needle (4), is equal or higher than greater of the forces defined in the following equations a and b:

a) $F_s = p_2 \cdot A_7$ when the needle (4) is at the highest operational position, defined by the system's maximal design pressure

b) $F_s = p_0 \cdot A_7$ when the needle (4) closes the outlet channel (8); and in these equations A_7 is the cross-sectional area of the needle (4) head, perpendicular to its axis at the channel (8) mouth at the actual operational situation.

8. Arrangement according to the claim 5 - 7, **characterized** by that the end of the needle (4) shaft is fixed to the valve disc (10) which is fixed to the diaphragm of the diaphragm or bladder accumulator (6).

9. Arrangement according to the claims 5 - 8, **characterized** by that when the nozzle valve (1) is used for maintaining pressure in a reverse osmosis system, the initial pressure (p_0) is chosen higher than the osmotic pressure of the saline water to be treated.

10. Arrangement according to the claims 5 - 9, **characterized** by that the nozzle valve (1) is that of an impulse turbine.