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(54) **Subsea compression system for well stream boosting**

(57) A subsea compression station is disclosed, comprising a separator (3), a compressor (1) and a pump (2), wherein the compressor is operable for compression and discharge of gas separated from a well stream ingested into the separator, and the pump is operable for pumping, liquid that is separated from the well stream,

and further comprising an electrical motor (4) drivingly connected to a compressor rotor having a compressor rotor shaft (7). The compressor rotor shaft is connectable to a pump rotor (11) via a speed reduction device (8) bringing the pump rotor in co-rotation with the compressor rotor at reduced speed.

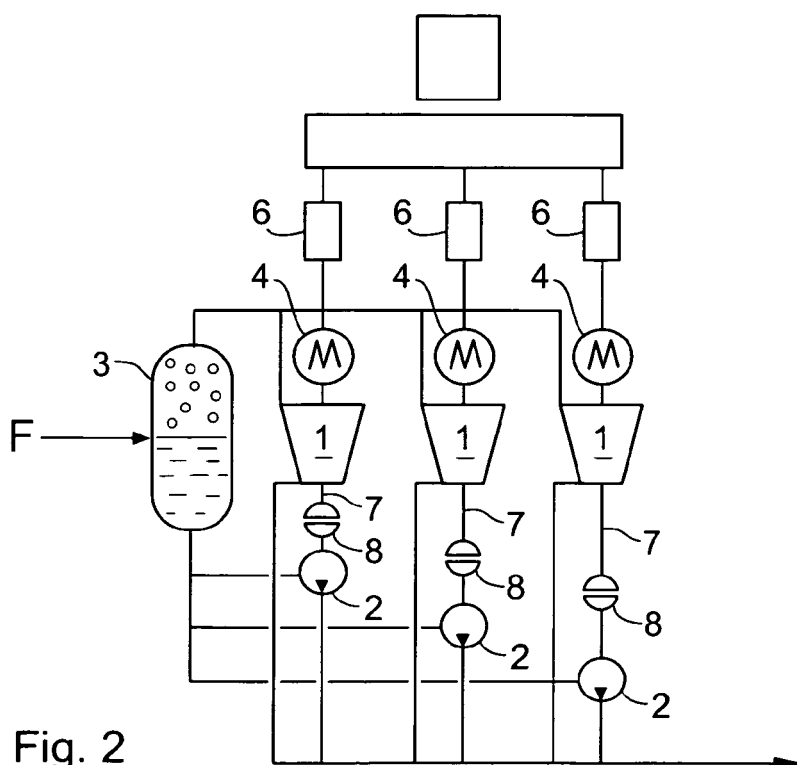


Fig. 2

Description

TECHNICAL FIELD OF THE INVENTION

[0001] The present invention relates to a subsea compression system for well stream boosting by compression of gas and pumping of liquid in subsea hydrocarbon production. More precisely, the present invention refers to arrangements on a compressor station forming part of a subsea compression system.

BACKGROUND AND PRIOR ART

[0002] Offshore gas production involves installations on the seabed which are controlled and powered from a land-based or sea-based terminal or host facility. Well fluid is transported via pipelines from a subsea production system to the receiving terminal to be further processed before the products are supplied to market. In the initial phases of production, the fluid reservoir pressure is usually sufficient for feeding the hydrocarbon fluids through the pipeline. Later in production, or in the case of very long distance between the well fluid reservoir and the receiving terminal, boosting of fluid pressure and flow may be required at one or more compression stations along the feed line in order to maintain flow rate and production level.

[0003] Compressors used in subsea compression stations are adapted to process wet gas containing a certain ratio of liquid. Above such a ratio, liquid pumps will be required. In the compression station, well fluid containing gas and liquid enters a separator or scrubber in which liquid is separated from the well stream and fed to the pump, providing predictable operating points for both the compressor and the pump with respect to liquid volume fraction. The pump is operated to pump the liquid downstream, typically by injecting the liquid into the compressed gas that is discharged from the compressor, whereby a re-mixed multiphase well fluid leaves the compression station at a raised pressure level and flow. Nevertheless, the subsea compression station may optionally be arranged for discharge of boosted gas and liquid flows via separate export lines.

[0004] Conventionally, each compressor and pump is driven by a dedicated electrical motor respectively which is supplied operating and control power via an umbilical connecting the compression station with its host facility. Each compressor or pump motor in the compression station requires for its operation an individual setup of power and control gear for a variable speed drive, such as subsea switchgear, wet-mate electrical connectors, high voltage electrical jumpers and electrical control system components, cooling and lubricating circuits including valves and flow or pressure control, etc.

SUMMARY OF THE INVENTION

[0005] The present invention aims to reduce the

number of components required in a subsea compression station configured for boosting a well stream containing gas and liquid.

[0006] The object is met in a subsea compression station comprising a separator, a compressor and a pump, wherein the compressor is operable for compression and discharge of gas separated from a well stream fed into the separator, and the pump is operable for pumping liquid that is separated from the well stream. An electrical motor is drivingly connected to a compressor rotor having a compressor rotor shaft, the compressor rotor shaft being connectable to a pump rotor via a speed reduction device bringing the pump rotor in co-rotation with the compressor rotor at reduced speed.

[0007] Thus, the dedicated pump motor and associated components such as power supply components, operation control, lubrication and cooling components etc., can be omitted which substantially reduces cost and complexity of the compression station.

[0008] The speed reduction device can be realized in alternative ways. A speed reduction ratio of about 4-5:1 can be assumed appropriate for a majority of subsea compressor/pump combinations.

[0009] For example, a mechanical clutch and gear reduction may be used as coupling and speed reduction device. A mechanical clutch coupling would however require slowing down the drive motor and compressor in order to connect the pump rotor to the compressor rotor, which revolves at considerably higher speed than the pump rotor in normal operating conditions.

[0010] In order to provide smooth acceleration of the pump it is preferred to connect the pump rotor to the compressor rotor shaft via a variable speed hydrodynamic torque converter, or alternatively, via an electrical hysteresis powered clutch, both of which provide torque transfer without physical contact between the driving compressor rotor shaft and the driven pump rotor.

[0011] In one preferred embodiment of the present invention, the compressor rotor shaft is fixedly connected to a housing of a fill-controlled hydrodynamic torque converter, and the pump rotor is fixedly connected to a turbine of the fill-controlled torque converter.

[0012] In another preferred embodiment, the compressor rotor shaft is fixedly connected to an impeller of a variable vane hydrodynamic torque converter, and the pump rotor is fixedly connected to a turbine of the variable vane torque converter.

[0013] In yet another preferred embodiment, the compressor rotor shaft is fixedly connected to a rotor of an electrical hysteresis powered clutch, and the pump rotor is fixedly connected to a hysteresis disk of the electrical clutch.

[0014] The present invention thus provides a common-drive and individual control concept wherein adjustable amount of torque can be transferred without physical contact from a compressor motor to a pump rotor in a subsea compression station, bringing the pump rotor in co-rotation with the compressor rotor at reduced speed. Con-

necting in and connecting out of the pump can be accomplished as required with respect to a liquid content in the supplied well stream, either by controlling the filling of a fill-controlled hydrodynamic coupling, or by adjusting the attack angle of vanes in a variable vane hydrodynamic coupling, or by regulation of electrical power supplied to an electromagnet of an electrical hysteresis powered clutch.

[0015] The present invention is advantageously applied to a subsea compression station wherein a centrifugal wet gas compressor and a positive displacement liquid pump are commonly driven and independently controlled.

[0016] Further advantages, advantageous features and embodiments of the invention will appear from the dependent claims and from the following detailed description of preferred embodiments.

SHORT DESCRIPTION OF THE DRAWINGS

[0017] The invention will be further explained below with reference made to the accompanying, schematic drawings. In the drawings,

Fig. 1 is a diagram illustrating schematically the setup of a prior art subsea compressions station;

Fig. 2 is a diagram corresponding to Fig. 1, illustrating the setup of a subsea compression station according to the present invention;

Fig. 3 is sectional view showing one preferred embodiment of the present invention;

Fig. 4 is a corresponding sectional view showing another preferred embodiment;

Fig. 5 is a sectional view showing yet another preferred embodiment, and

Fig. 6 is a simplified diagram illustrating an implementation of the present invention.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

[0018] An overview of the main modules and parts of a subsea compression station for well stream boosting is illustrated schematically in the diagram of Fig. 1. The compression station receives bi-phase or multi-phase well fluid from at least one subsea production system and feeds boosted well fluid into one or several export pipe lines for further transport to a receiving terminal. The compression station comprises a compressor module including one or more compressors 1, a pump module including at least one pump 2, and a separator/scrubber module including a separator 3. The separator 3 is designed for liquid/gas separation and may additionally be

structured for dissolving liquid slugs, for hydrate prevention and for sorting out solid particles entrained in the well stream, for gas scrubbing etc., so that compressible gas (wet gas) mainly is delivered to the compressor intake. The compressor(s) 1 is designed for raising the pressure of the gas and discharging the gas at an elevated pressure into the export pipeline. The pump(s) 2 is designed for injecting the excess liquid, at an elevated pressure, to the gas flow discharged from the compressor.

[0019] High voltage power, low voltage power, hydraulic, control and utilities are supplied from the host facility via an umbilical connected to the subsea compression station. Utility and control power is distributed to consumers on the subsea compression station via transformers, high voltage cables and wet-mate electrical connectors, switchgear, electrical jumpers, circuit breaker modules, etc. Since the compressor(s) and pump(s) are individually driven by dedicated variable speed drive (VSD) electrical motors 4 and 5, respectively, utility and control power equipment need to be individually installed for each motor. In the drawings, the dedicated utility and control power equipment is schematically represented through VSD-blocks 6.

[0020] In addition, each motor requires separate flexible couplings, guiding and landing devices, valves and fluid lines for cooling, lubrication and barrier pressure, on the subsea compression station.

[0021] Fig. 2 is an overview of a subsea compression station which is setup in utilization of the present invention. A noticeable difference in the architecture of Fig. 2 is the significantly reduced number of VSD-blocks 6, which can be reduced by 50 % as the result of driving the pump(s) 2 with the compressor motor(s) 4, via the compressor rotor shaft 7 and an interconnected speed reduction device 8 effective for bringing the pump rotor in co-rotation with the compressor rotor at reduced speed.

[0022] Naturally, the reduction in number of components required in the subsea compression station applies to all components that would otherwise have been involved in the operation of the omitted motor.

[0023] Fig. 3 illustrates a first preferred embodiment of the invention, relying on a speed reduction device in the form of a variable speed, hydrodynamic torque converter 9.

[0024] In the embodiment of Fig. 3, the compressor rotor shaft 7 is fixedly connected to a housing 10 of a fill-controlled hydrodynamic torque converter, and the pump rotor 11 is fixedly connected to the turbine 12 of the fill-controlled torque converter. The amount of torque and output speed that is transferred from the compressor rotor shaft to the pump rotor depends on the fill level of hydraulic fluid in the housing, which can be controlled and modified during operation. For a slow start of the pump, acceleration of pump rotor can be controlled through the speed by which the housing is filled, and the appropriate speed reduction is achieved through a cor-

responding fill level in the housing.

[0025] Alternatively, and illustrated in Fig. 4, the compressor rotor shaft 7 may be fixedly connected to an impeller 13 of a variable vane hydrodynamic torque converter 14, whereas the pump rotor 11 is fixedly connected to the turbine 15 of the variable vane torque converter. The amount of torque and output speed that is transferred from the compressor rotor shaft to the pump rotor depends on the angle of attack of guide vanes 16 arranged adjustable on a stator 17 in which the impeller is housed, and can be controlled and modified during operation through actuation of a vane angle shifting mechanism 18 supported on the stator.

[0026] Fig. 5 illustrates another preferred embodiment of the invention, relying on a speed reduction device in the form of an electrical hysteresis powered clutch 19.

[0027] In Fig. 5, the compressor rotor shaft 7 is fixedly connected to a rotor 20 of the electrical hysteresis powered clutch, and the pump rotor 11 is fixedly connected to a hysteresis disk 21 of the electrical clutch. The hysteresis disk 21 passes an annular gap in the rotor 20 without physical contact between disk and rotor. The rotor 20 rotates in a magnetic field created as current/voltage is applied to an electromagnet 22 near the rotor. As the rotor rotates, the hysteresis disk is pulled in rotation in result of magnetic drag between the rotor 20 and the hysteresis disk 21. Since the hysteresis disk becomes magnetized in relation to the strength of the magnetic flux created by the electromagnet, the amount of torque and output speed that is transferred from the compressor rotor shaft to the pump rotor depends on the amount of current/voltage that is applied to the electromagnet, which can be controlled and modified during operation.

[0028] A subsea compression station laid out in accordance with the common-drive and individual control concept provided by the present invention is illustrated schematically in Fig. 6.

[0029] Without explicitly being explained in detail with reference to Fig. 6, a fully equipped and operative subsea compression station typically comprises import and export well stream manifolds and valves, flow and pressure meters, re-circulation lines and valves, anti-surge control circuit and valves, lubrication and barrier fluid circuits and valves, umbilical head end, transformers, coolers, sand trap etc., and other equipment which is conventionally found on a subsea compression station. For reasons of clarity, the detailed structure and organization of modules and units which are of subordinated significance in this connection have been excluded from Fig. 6.

[0030] In a subsea compression station implementing the invention, well fluid F is fed into a separator and slug catcher 3 configured for separation of gas and liquid. The separator houses a mixer pipe 23 wherein gas and remaining liquid are evenly distributed before delivery to the intake of compressor 1 via wet gas fluid line 24. The level of liquid in the separator 3 is controlled through drain pipe 25 from which excess liquid is withdrawn and delivered to pump 2 via self-filling liquid line 26. The compres-

sor 1 and pump 2 are commonly driven by a single, variable speed electrical motor 4, the output torque and speed of which is reduced by means of a speed reduction device 8 interconnected between the pump and the compressor.

[0031] Utility and control power is supplied to the motor 4 via VSD-block 6 and umbilical head end block 27 representing the necessary high and low voltage circuits, wet mate connectors, switchgear, circuit breakers, etc. Operating fluid or pressure for the fill-controlled torque converter, or control power for the variable vane torque converter, or magnetizing current/voltage for the electrical hysteresis clutch, as required in each respective embodiment, is supplied to the speed reduction device 8 from the host facility/top side terminal via power supply line 28. Control of power supply for actuation of the speed reduction device 8, i.e. coupling and de-coupling with the compressor rotor shaft, is accomplished in response to a detected liquid fraction or level in the separator 3 and communicated to actuator valves or actuator switches in the speed reduction device via pilot line 29.

[0032] The compressor(s) used in the subsea compression station is designed for a substantial elevation of the gas pressure, such as from about 40 bar at compressor intake to about 120 bar at compressor discharge, e.g. Heavy duty centrifugal wet gas compressors are generally used in this connection, typically operating at a power range of one or several tens of megawatt and at rotational speeds in the order of 8-12,000 rev per min.

[0033] The pump(s) used in the subsea compression station is designed for boosting the liquid stream up to a pressure required for introduction into the gas discharged from the compressor. Positive displacement pumps are useful in this connection, operating at a power range of hundreds of kilowatt and at rotational speeds of about 1,500-4,000 rev per min. Thus in most compressor/pump combinations a speed reduction ratio of about 4-5:1 will be appropriate. However, positive displacement pumps or centrifugal pumps rotating at other operational speeds may alternatively be used, requiring different speed reduction ratios. Nevertheless, the present invention provides great freedom in the choice of pump/compressor combination since both the fill-controlled or variable vane hydrodynamic torque converters as well as the electrical hysteresis clutch can be controlled between zero and 100 % lockup between driving and driven components, depending obviously on the output torque required.

[0034] Although referred to as a compressor rotor shaft 7 in the description and appended claims, the element 7 shall be understood to include any shaft or axle that is connectable to or constitutes an integrally formed extension from the compressor rotor and which co-rotates with the compressor rotor.

[0035] Although referred to as a pump rotor 11 in the description and appended claims, the element 11 shall be understood to include any shaft or axle that is connectable to or constitutes an integrally formed extension from the pump rotor and which co-rotates with the pump

rotor.

[0036] The invention is not limited to the in-line, co-axial assembly which is schematically illustrated in the drawings. Instead, the pump and compressor may alternatively be arranged on parallel axes, or even on crossing axes, with intermeshing gears or bevel gears transmitting torque and rotation from the compressor motor to the pump rotor.

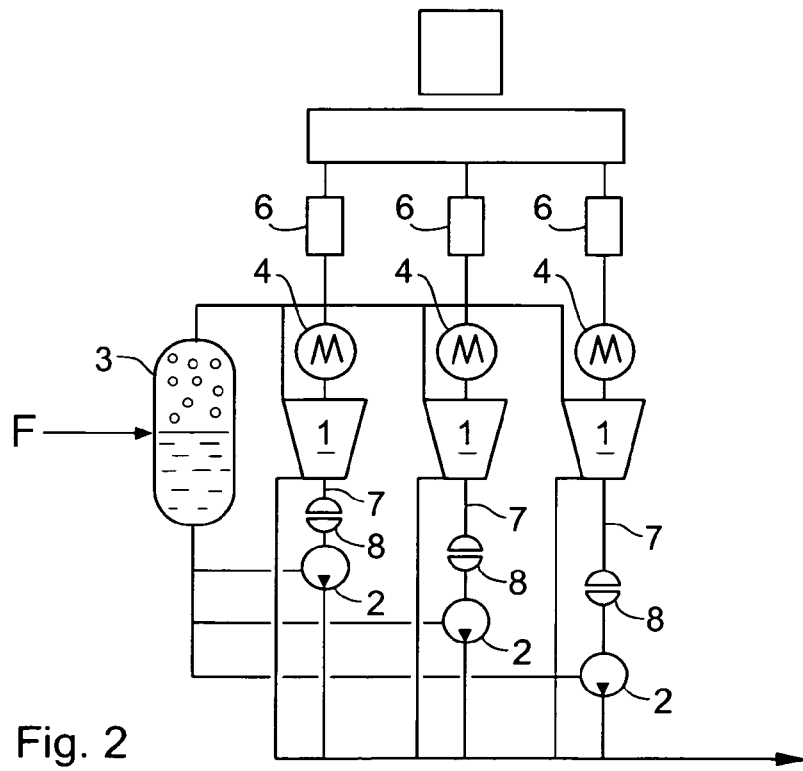
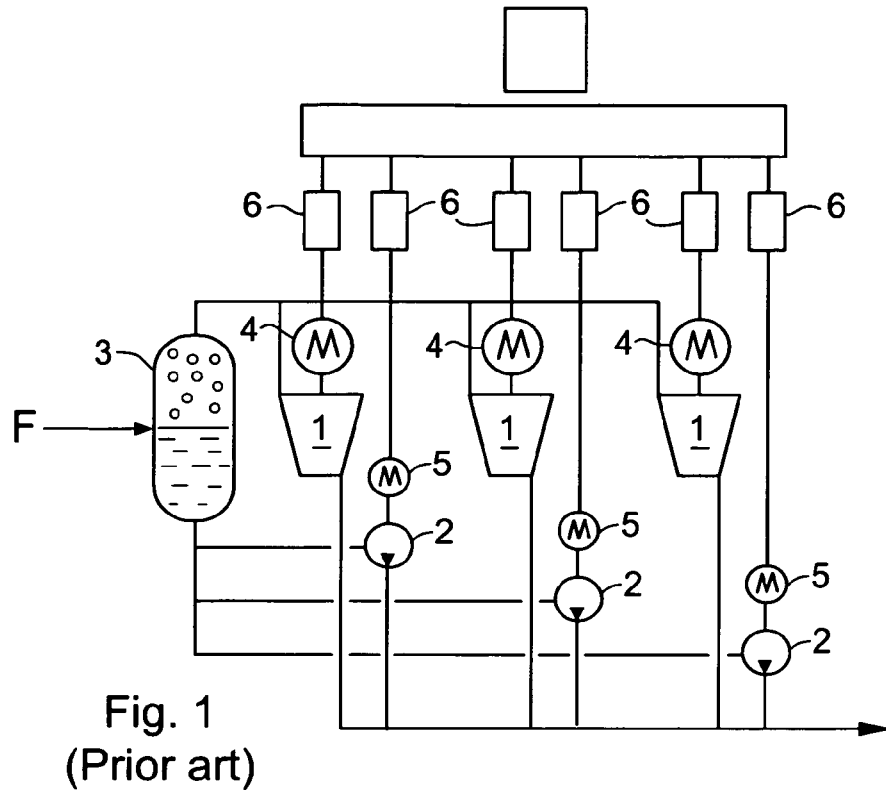
[0037] The invention is not in any way restricted to the embodiments described above. On the contrary, many possibilities to modifications thereof will be apparent to a person skilled in the art without departing from the basics of the invention such as defined in the appended claims.

hysteresis disk (21) of the electrical clutch.

7. The compression station of any of claims 1-6, wherein the speed reduction device has a speed reduction ratio of about 4-5:1.
8. The compression station of any of claims 1-7, wherein a centrifugal wet gas compressor and a positive displacement liquid pump are commonly driven and independently controlled.

Claims

1. A subsea compression station comprising a separator (3), a compressor (1) and a pump (2), wherein the compressor is operable for compression and discharge of gas separated from a well stream ingested into the separator, and the pump is operable for pumping liquid that is separated from the well stream, and further comprising an electrical motor (4) drivingly connected to a compressor rotor having a compressor rotor shaft (7), **characterized in that** the compressor rotor shaft is connectable to a pump rotor (11) via a speed reduction device (8) bringing the pump rotor in co-rotation with the compressor rotor at reduced speed.
2. The compression station of claim 1, wherein the speed reduction device is a variable speed hydrodynamic torque converter (9; 14).
3. The compression station of claim 2, wherein the compressor rotor shaft (7) is fixedly connected to a housing (10) of a fill-controlled hydrodynamic torque converter (9), and the pump rotor (11) is fixedly connected to a turbine (12) of the fill-controlled torque converter.
4. The compression station of claim 2, wherein the compressor rotor shaft (7) is fixedly connected to an impeller (13) of a variable vane hydrodynamic torque converter (14) and the pump rotor (11) is fixedly connected to a turbine (15) of the variable vane torque converter.
5. The compression station of claim 1, wherein the speed reduction device is an electrical hysteresis powered clutch (19).
6. The compression station of claim 5, wherein the compressor rotor shaft (7) is fixedly connected to a rotor (20) of the electrical hysteresis powered clutch and the pump rotor (11) is fixedly connected to a



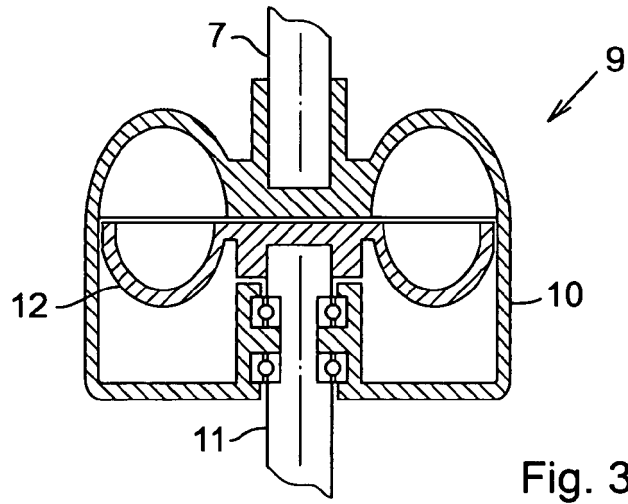


Fig. 3

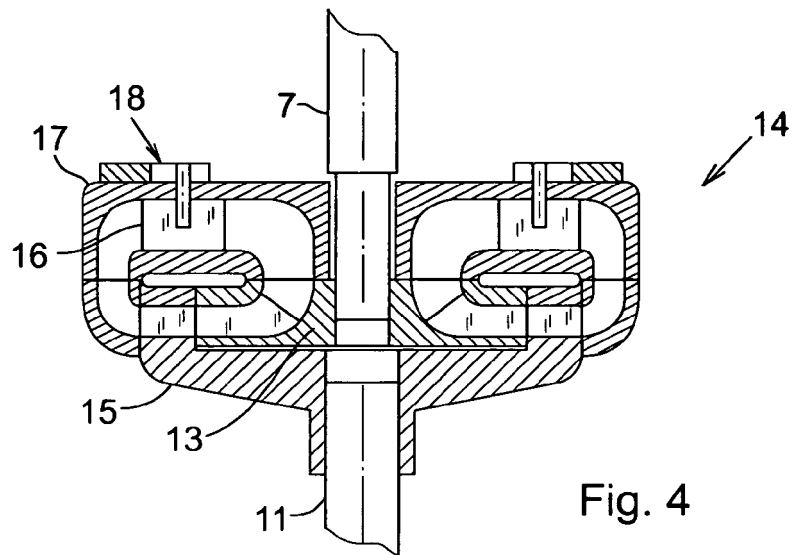


Fig. 4

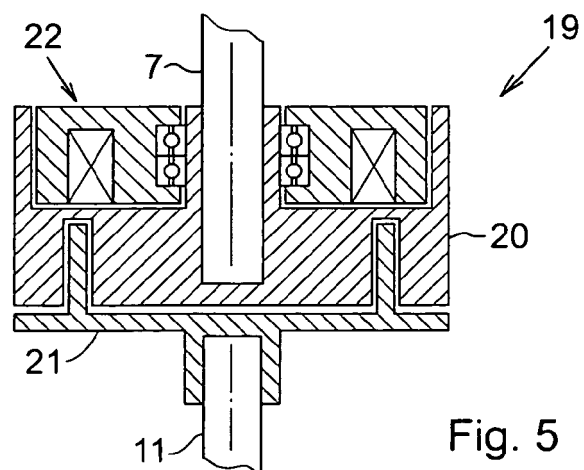


Fig. 5

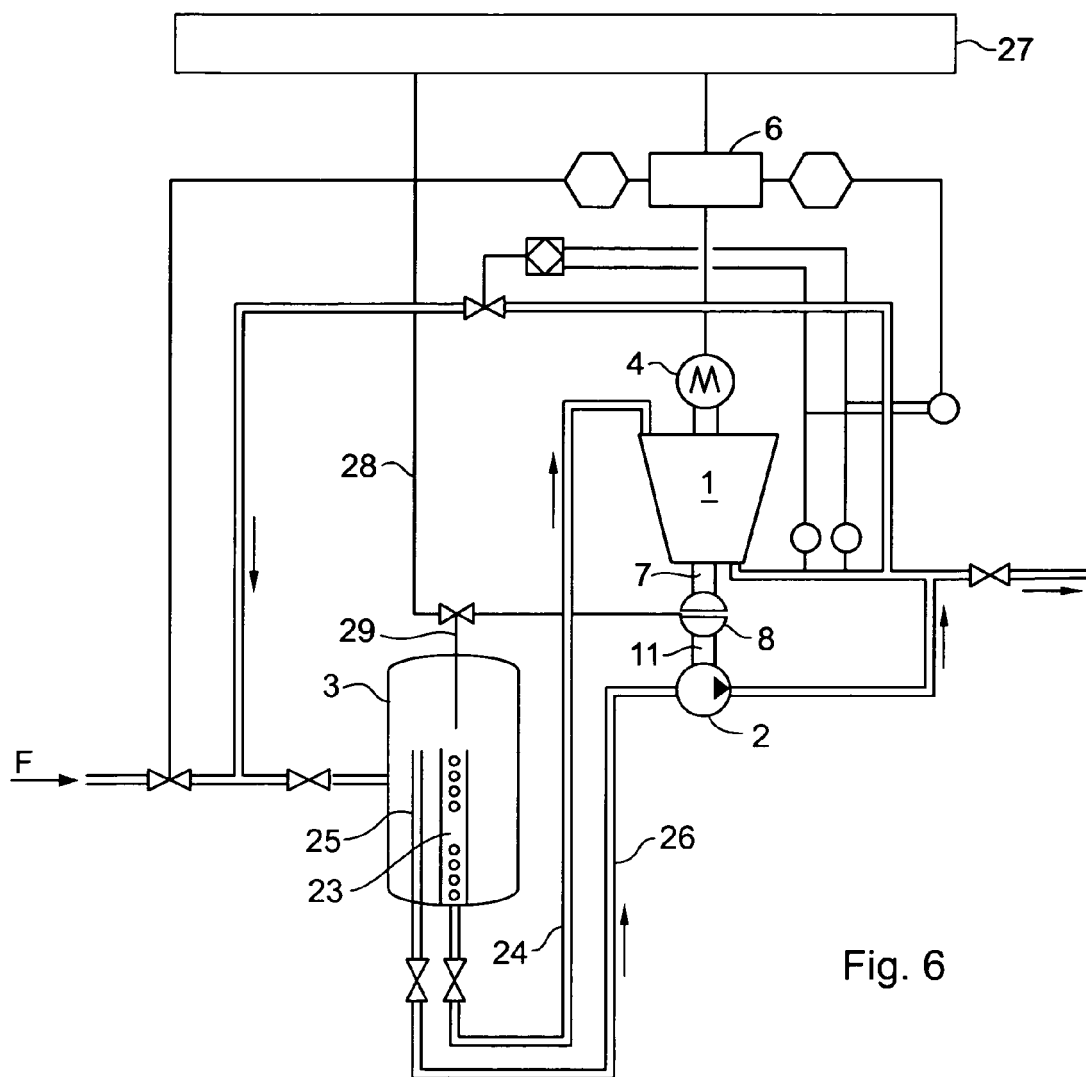


Fig. 6