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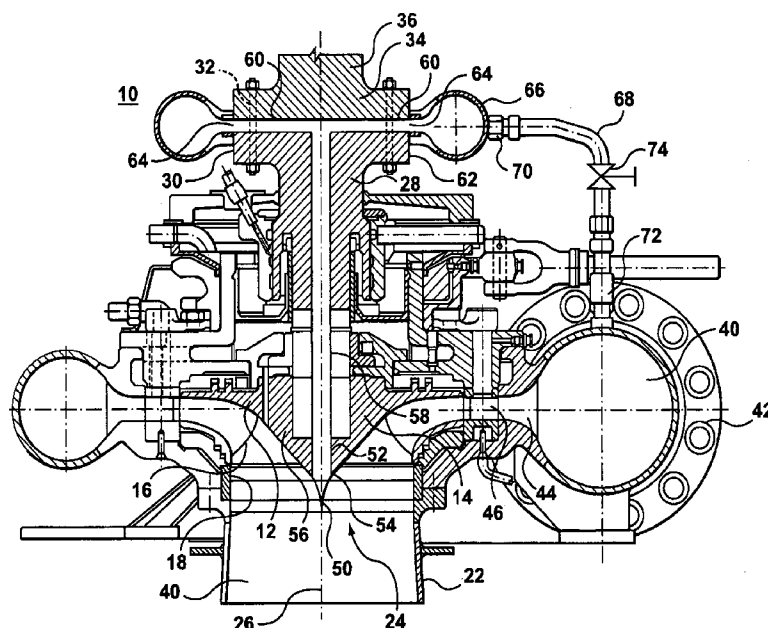
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(54) Title: LIQUID CONTROL JET DURING PART LOAD OPERATION IN A HYDRAULIC TURBINE



(57) Abstract: A method and system to mitigate the pressure fluctuations in hydraulic turbines, operated at partial load, by injecting high velocity control jet (50) or jets of liquid downstream of the turbine runner, on the upper portion of the draft tube (22), along the machine axis; the liquid jet(s) flow rate can be adjusted continuously depending on the pressure fluctuation level in the draft tube, so as to control the swirling flow downstream of the runner and avoid helical vortex breakdown at partial load regimes, thus eliminating the main cause of pressure fluctuations.

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For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

LIQUID CONTROL JET DURING PART LOAD OPERATION IN A HYDRAULIC TURBINE

FIELD OF THE INVENTION

The present invention relates to a hydraulic turbine having one or more control jets of liquid injected with high velocity axially downstream of the turbine runner and into an upper portion of the turbine draft tube, during part load operation of the turbine, to control the swirling flow and mitigate both helical vortex breakdown and its associated pressure fluctuations.

BACKGROUND OF THE INVENTION

Until recently, hydraulic turbines have been operated close to peak efficiency. In the neighborhood of this optimum operating point, dynamic forces on the turbine components are generally low, with the exception of transient conditions such as load rejection and surge.

The variable demand on the energy market, as well as the limited energy storage capabilities, requires a great flexibility in operating hydraulic turbines. As a result, hydraulic turbines tend to be operated over an extended range far from the best efficiency point. In particular, Francis turbines, which have a fixed-pitch runner, have a high level of residual swirl at the draft tube inlet as a result of the mismatch between the swirl generated by the wicket gates (guide vanes) and the angular momentum extracted by the turbine runner when operating at part load conditions. In the turbine draft tube the flow exiting the runner is decelerated, thereby converting the excess of the kinetic energy into static pressure. The decelerated swirling flow often results in breakdown of the normal vortex associated with flow of liquid in the draft tube which gives rise to the development of a central quasi-stagnation region in the draft tube. The vortex breakdown is now recognized as a primary cause of severe pressure fluctuations or pressure pulsations experienced in the draft tube of a hydraulic turbine operating at part load. The pressure pulsations are believed to be caused by the transformation of an axis-symmetrically swirling vortex flow into one or more precessing helical vortices as the operating condition shifts towards part load. The

precessing motion of the helical vortex results in a fluctuating pressure on any stationary point of the draft tube. In addition, a limited quantity of air or water vapor in the liquid flow provides a degree of elasticity, termed cavitation compliance, and this elasticity can lead to a form of resonance in the draft tube excited by the precessing inhomogeneous pressure field associated with the core of the spiral vortex flow.

Many different solutions have been proposed with respect to the problem of draft tube instability including altering blade design, the introduction of vanes in the draft tube, and the injection of air into a recirculation region surrounded by the vortex rope. The air injection produces an essentially axis-symmetrical stable flow, or a hollow air core surrounded by the swirling water flow. The air injection changes the breakdown of the vortex form from a spiral to a bubble. The injection of relatively small amounts of air have small effects on the efficiency of the turbine operation while considerably reducing the part load pressure swings. However, the vortex rope and the excitation of the rope continues to exist.

Accordingly, there is a need to develop hydraulic turbines for present day hydroelectric facilities that operate efficiently not only under normal load conditions but also at low or partial load conditions, without being subjected to the severe pressure fluctuations originating in the draft tube as a result of helical vortex breakdown in the decelerated swirling flow downstream of the runner.

SUMMARY OF THE INVENTION

The present invention relates to controlling swirling flow downstream of a hydraulic turbine runner by the axial injection of high velocity jet or jets of liquid at the runner outlet or draft tube inlet. The control jet or jets of liquid act on the flow of liquid in the draft tube by mitigating breakdown of the vortex flow path of this liquid and thereby diminishing or eliminating draft tube pressure pulsations experienced during part load operation of the turbine.

By “high velocity ” it is meant that the axially directed jet of liquid has a velocity that is greater than the mean axial velocity of liquid flowing at the runner outlet so as to provide the benefit of the present invention. This high velocity of the liquid control jet or jets may be as much as about 2 to 4 times or more greater than the mean axial velocity of the liquid flowing at the runner outlet. It should be understood that the high velocity of the liquid control jet or jets will vary depending on the location of injection of the liquid control jet or jets and the number of control jets utilized. It should be further understood that by making reference to a control jet or jets of high velocity liquid being injected axially of the turbine it is meant the control jet or jets, may be directed along the turbine axis, parallel to the turbine axis, or converging on a focal point adjacent the upper portion of the draft tube lying on the turbine axis or a parallel axis adjacent to the turbine axis. Further the jet or jets may be located offset from the turbine axis by, for example but not limited thereto, 10 percent of the diameter of the turbine runner and still be considered to be located relative to a central axis of the turbine runner.

The control jet or jets are preferably operated when the turbine is operating at part load conditions. The control jet or jets are injected from at least one nozzle head device positioned relative to a central axis for the turbine runner and adjacent to an upper portion of the draft tube whereby the jet or jets of liquid are injected downstream of the runner. The at least one nozzle head device has at least one nozzle from which a corresponding high velocity liquid control jet is emitted into the draft tube. In one embodiment, the turbine has a rotatable runner mounted above the draft tube and the runner has a crown portion that houses the at least one nozzle head device. In an alternative embodiment, the at least one nozzle head device may be supported in an upper portion of the draft tube below and spaced from the crown of the turbine runner.

The at least one nozzle head device may comprise a single nozzle or a plurality of nozzles arranged in one or more circular arrays, or a single annular nozzle.

In accordance with the present invention there is provided a hydraulic turbine comprising a passageway permitting liquid to pass through the turbine and a draft tube defining a portion of the passageway through which liquid normally flows in a vortex flow path during optimal turbine operating conditions. A rotatable runner is mounted upstream of the draft tube and rotates about a central axis passing through the runner and extending into the draft tube. At least one nozzle head device is positioned relative to the central axis of the runner and adjacent to an upper portion of the draft tube. The at least one nozzle head device has at least one nozzle from which a corresponding control jet of high velocity liquid is injected axially downstream of the runner and into liquid flowing into the upper portion of the draft tube during part load turbine operation so as to mitigate breakdown of the vortex flow path.

In accordance with the present invention there is provided a method of controlling part load operation of a hydraulic turbine during part load conditions having a runner, a draft tube located downstream of the runner and a liquid passageway extending through the runner and the draft tube. The method comprises the step of injecting one or more control jets of high velocity liquid axially of the turbine, downstream of the turbine runner and into at least an upper portion of the draft tube.

It is envisaged that the method may further include the step of locating the one or more control jets centrally of the runner prior to the step of injecting. Further, the jet or jets may be located offset from the turbine axis.

Further during the step of injecting the one or more control jets, the one or more control jets may be injected in one direction selected from the group consisting of along an axis of the turbine, parallel to the turbine axis, converging on a focal point adjacent the upper portion of the draft tube lying on the turbine axis and a parallel axis adjacent to the turbine axis.

BRIEF DESCRIPTION OF THE DRAWINGS

For a better understanding of the nature and objects of the present invention reference may be had to the accompanying diagrammatic drawings in which:

FIG. 1A is an elevation view, partially in cross-section, of a Francis turbine showing a nozzle head device for emitting a control jet positioned in the crown above the draft tube;

FIG. 1B illustrates an alternative embodiment for the nozzle head device for emitting a control jet where the nozzle head device is in the runner crown exclusively;

FIG. 2 illustrates an alternative embodiment for the nozzle head device for emitting a control jet where the nozzle head device is positioned in the draft tube spaced below the crown;

FIGs. 3A and 3B show comparative velocity contours for water flowing through the draft tube;

FIGs. 4A and 4B show comparative pressure contours for water flowing through the draft tube;

FIGs. 5A through 5D show alternative embodiments for the arrangement of nozzles in the nozzle head device.

DETAILED DESCRIPTION OF THE INVENTION

The present invention relates to a hydraulic turbine having one or more liquid control jets axially directed downstream of a turbine runner and into an upper portion of a draft tube. The present invention is intended for use in fixed-pitch hydraulic turbines and preferably finds application in propeller and Francis type turbines.

Referring to FIG. 1A there is shown an exemplary hydraulic turbine installation 10 suitable for use in the generation of hydro-electricity. The turbine installation 10 comprises a Francis turbine 12 having a crown 14, runner blades 16, and a band 18. The Francis turbine runner 12 is adapted to rotate within a stationary casing 42. Below the Francis turbine runner 12 is located a draft tube 22. It should be understood that while a Francis turbine runner is shown the runner could also be a propeller type runner. Only a portion of the draft tube 22 is shown. The upper portion

24 of the draft tube 22 is shown to have a vertically extending central axis 26. The axis 26 is also the central axis for the runner 12 and the axis of the hydraulic turbine 10.

The upper portion of the crown 14 is connected to shaft 28. The shaft 28 has a coupling flange 30 which is connected by bolts 32 to a coupling flange 34 of a generator shaft 36. Rotation of the Francis runner 12 causes the shaft 28 to rotate and hence, the generator shaft 36 to rotate. The generator shaft 36 is connected to a generator (not shown) which generates electricity in response to the rotating action of the Francis turbine 12.

The Francis turbine 12 rotates as a result of water moving along water passageway 40, from the spiral casing 42 past stay vanes 44, past wicket gate 46, the runner blades 16 and into the draft tube 22.

In accordance with the embodiment shown in FIG. 1A, a control jet 50 is injected into the water flowing in the top portion 24 of the draft tube 22. A nozzle head device 52 comprise an end portion of conduit 58 that passes through the centre of the crown 14. The head device 52 has a nozzle 54 from which the control jet 50 is injected into the water or liquid flowing through the draft tube 22. The crown 14 has a crown tip portion 56 that houses the nozzle head device 52.

Water under pressure is supplied to the crown tip portion 56 and the nozzle head device 52 by the conduit 58 passing through shaft 28. The conduit 58 is connected to radially inwardly extending conduits 60. The shaft 28 has an outside wall 62 with one or more liquid ports 64 contained therein. The radially inwardly directed conduits 60 are connected with the nozzle 54, via conduit 58 and nozzle head device 52 and transport high pressure water from the liquid ports 64 to the nozzle 54. In the illustrated embodiment the inlet ports 64 are located between the coupling flanges 30 and 34 which is also referred to herein as being located on the outside wall of the shaft 28 as the coupling 30 forms part of the shaft 28. While the shafts 28 and 36 are illustrated as being solid, in practice, they are typically hollow.

A stationary liquid collection chamber 66 is mounted in surrounding sealing relation with the hollow shaft 28, or in the illustrated embodiment the coupling flanges 30, 34. Stationary liquid collection chamber 66 directs pressurized water into the ports 64. The stationary liquid or water collection chamber 66 is connected to a liquid or water bypass supply conduit 68 at an end portion 70 thereof. The liquid bypass supply conduit 68 has an opposite end portion 72 coupled in sealing relation with the spiral casing 42 and communicates liquid from the spiral casing 42 to the liquid collection chamber 66. A regulating valve 74 is located in the pressurized liquid supply conduit 68. The valve 74 controls the flow rate of the liquid supplied to the liquid chamber and is adapted to switch the control jet from an off condition to an on condition and to vary the flow rate of the control jet depending on the part load operating conditions of the turbine installation 10. In the embodiment shown, the regulating valve 74 is located upstream of the nozzle 54 so as to control the flow rate of the water and hence the resultant velocity of the "high velocity" control jet 50 emitted from nozzle 54. It should be understood that the regulating valve 74 is able to switch the supply of water to liquid collection chamber 66 off when the turbine is operating at optimal load conditions. As a result no water is emitted from nozzle 54. In the embodiment of FIG. 1A, the control jet 50 is emitted from the nozzle 54 of nozzle head device 52 which is positioned centrally of, and adjacent to, upper portion 24 of draft tube 22 within the crown 14. Producing the water jet at the crown tip takes advantage of the hollow turbine shaft, and benefits from a high-pressure water supply from upstream in the turbine spiral casing.

It should be understood that FIG. 1A illustrates an exemplary jet generation and control system comprising head device 52, conduits 58,60, water collection chamber 66, conduit 68, and valve 74 and that alternative embodiments for supplying water under pressure to the head device 52 will be readily understood to a person skilled in the art.

In FIG. 1B there is shown a cross-section through a turbine 10 comprising a spiral casing 111, stay vanes 113, guide vanes 112, Francis runner 109, and draft tube 114. A passageway 115 extends through the turbine 110. The runner crown 120 comprises

a central cavity 122 connected with the high pressure side 124 of the runner 109 by open tubes 126. A nozzle head device 128 has a needle 132 and a nozzle 130 from which the high velocity liquid control jet 50 is emitted into the upper portion 140 of the draft tube 114 from the runner crown 120. An adjustment mechanism 134 is driven by an active control device 136 for adjusting the position of the nozzle head device 128 so as to control the speed of the high velocity liquid control jet 50.

One or more pressure sensors 142 are mounted in the draft tube 114 adjacent a sidewall thereof near the upper portion 140 of the draft tube 114. The pressure sensors 142 measure the water pressure in the upper portion of the draft tube 114 and relay these measurements to the active control device 136 which in turn controls movement of the nozzle head device 128 in order to adjust the velocity of the high velocity liquid control jet 50. When in an open position for the nozzle head device 128, water from the high pressure side 124 of the runner 109 is supplied through tubes 126 the cavity or water chamber 122 to the nozzle 130. As a result a liquid control jet 50 will be emitted from the crown 120 of the runner into upper portion 140 of the draft tube 114 also known as the draft tube inlet. The velocity or flow rate of the liquid control jet 50 is controlled by the position of the nozzle head device 128 depending on the pressure measured by the pressure sensors 142. The nozzle head device 128 is closed when the turbine is not operating at partial load operating conditions. This system of jet generation has the advantages that the jet generation system concerns a single component of the turbine, namely the runner. The system of generation does not imply any water tightness problems, and can be implemented in situ for existing runners and all the system components, except for the runner cavities and tubes and can be considered to be a turnkey jet generation type of kit.

Referring to FIG. 2 there is shown an alternative embodiment wherein the nozzle head device 80 is spaced from the crown 14 of the turbine 10. The nozzle head device 80 comprises a nozzle 82 from which the liquid jet 50 is injected vertically axially along the axis 26 of the draft tube 22 adjacent the upper portion 24 of the draft tube 22. The nozzle head device 80 further comprises a plurality of supporting and liquid supplying conduits 84 interconnecting the head 82 with manifold 86 located on the outside wall

of the draft tube 22. The manifold 86 is connected via bypass supply piping 88 to the scroll 40. A regulating valve 90 is located to control the pressure of the liquid or water supplied to nozzle 82 and hence the “high velocity” of the liquid control jet 50. In this embodiment, water under pressure is supplied from the scroll 40 through the wall of the draft tube 22 and not through the crown 14 of the Francis turbine 12.

Referring to FIGS. 3A, 3B, 4A and 4B there are shown computer simulations of velocity and pressure contours of water flowing in the draft tube 22 that occur at part load conditions. FIGS. 3A and 3B show velocity contours of water flowing within the draft tube at part load conditions. In FIG. 3A, no control jet has been injected into the draft tube. In FIG. 3B, a liquid control jet has been injected into the draft tube. In FIG. 3A, where no jet is employed, there is shown a single helical draft tube vortex rope 94. In FIG. 3B where the control jet is in operation, the central low pressure region indicated by the iso-surface has been greatly reduced and its shape has changed from a helical shape to a slightly off-centre extended cone 96. In FIG. 4A, the jet is not employed and the pressure contour shows strong circumferential variations in the vortex flow of the water in the draft tube at 98, which associated with the precession motion result in severe pressure fluctuations. In FIG. 4B, where the control jet is employed there appears to be no breakdown in the low pressure area associated with the vortex at area 100.

By injecting a control jet of high velocity liquid axially into the draft tube, the precession frequency is altered in the draft tube and, eventually, by eliminating the quasi-stagnant central region, the control jet prevents or reduces development of vortex ropes in the draft tube liquid flow. As a result, the control jet addresses directly the vortex rope occurrence development thus mitigating the main source of pressure fluctuations, or at least it alters the precession frequency and reduces significantly the pressure fluctuations amplitude. Injecting a control jet of liquid is different from the air admission at the tip of the crown since the control jet of liquid is aimed at controlling or eliminating the vortex breakdown. Further when the control jet is not needed during turbine operation, the control jet can be switched off.

By avoiding the helical vortex breakdown the overall performance of the draft tube at part load is significantly improved by reducing the hydraulic losses due to severe flow non-uniformities and unsteadiness.

The control jet provides an active control of the swirling flow downstream of the runner. The control jet uses a fraction of the overall turbine discharge. The jet discharge bypasses the turbine bladed region and produces no power at the turbine shaft. However, the reduction in efficiency as a result of the jet discharge bypassing the turbine bladed region is lower than expected. This is because of reduction of hydraulic losses due to the precessing vortex rope compensating for hydraulic energy spent on the jet. In addition, the control jet has the benefit of diminishing the severe pressure pulsations and the draft tube instability at partial discharge.

Referring to FIGS. 5A through 5D there is shown embodiments of the header portion 82 for a single nozzle head device 80 from Fig 2.. It should be understood that multiple nozzle head devices could be employed or multiple head portions 82 for each nozzle head device could be employed for alternative embodiments. However, in FIG. 5A, a single nozzle 102 for emitting the control jet 50 is located to direct the jet 50 along axis 26 of the draft tube. Alternatively, this jet 50 could be directed along an axis parallel to and offset from the axis 26. In FIG. 5B, the plurality of nozzles 102 are arranged in a circular array about the central axis 26. This will result in a plurality of jets being emitted from the nozzles 102. Alternatively the jets could be arranged in a circular array an axis parallel to and offset from the axis 26. The nozzles 102 can be arranged to emit the jets either parallel to the axis 26 or the jets may converge towards each other with a focal point lying on the axis 26, or the jets may be directed to focus on an axis parallel to the central axis 26. In FIG. 5C, two circular arrays of nozzles 102 are arranged concentrically about the central axis 26. In FIG. 5D, a single nozzle in the form of annular ring 102 is arranged around the axis 26. In alternative embodiments to FIGS. 5A to 5D, the location of the nozzles can be chosen to direct the control jet or jets to be offset from the control axis 26 by as much as 10% of the diameter of the draft tube 22.

The utilization of the control liquid jet or jets of the present invention: a) successfully addresses directly the main cause of the flow instability, rather than the effects; b) does not require geometrical modifications of the runner outer shape; c) is continuously adjustable according to the operating conditions, and can be switched-off when it is not needed; and, d) although a fraction of the discharge may bypass the bladed region, the overall turbine efficiency suffers marginally, and may be improved, due to improvement in both runner and draft tube efficiencies when the control jet is on at part load operating conditions.

While the invention has been described in connection with what is presently considered to be the most practical embodiments of the hydrodynamic approach of controlling the swirling flow and mitigating the helical vortex breakdown together with the associated severe pressure fluctuations by using axial high velocity liquid control jet or jets, it is to be understood that the invention is not to be limited thereto, but on the contrary, is intended to cover various modifications and equivalent arrangements as would be understood by a person skilled in the art of hydraulic turbines.

CLAIMS

What is Claimed:

1. A hydraulic turbine comprising:

a passageway permitting liquid to pass through the turbine;

a draft tube defining a portion of the passageway through which liquid normally flows in a vortex flow path during optimal turbine operating conditions;

a rotatable runner mounted upstream of the draft tube and rotating about a central axis passing through the runner and extending into the draft tube;

at least one nozzle head device positioned relative to the central axis of the runner and adjacent to an upper portion of the draft tube, the at least one nozzle head device has at least one nozzle from which a corresponding control jet of high velocity liquid is injected axially downstream of the runner and into liquid flowing into the upper portion of the draft tube during part load turbine operation, so as to mitigate breakdown of the vortex flow path.

2. The hydraulic turbine of claim 1 wherein the at least one nozzle locates the corresponding control jet of high velocity liquid in one position of along a central axis of the turbine and offset from the turbine central axis.

3. The hydraulic turbine of claim 1 wherein the runner has a crown portion and the crown portion houses the at least one nozzle head device.

4. The hydraulic turbine of claim 3 wherein the runner comprises a jet generation and control system located in one of the crown portion and a shaft portion for the runner.

5. The hydraulic turbine of claim 3 wherein the at least one control jet of high velocity liquid is ejected from the nozzle axially into a central portion of the vortex flow path of the liquid flowing in the draft tube.

6. The hydraulic turbine of claim 1 wherein the at least one nozzle head device further comprises at least one valve located upstream of the at least one nozzle for controlling the pressure of the liquid of the corresponding control jet.

7. The hydraulic turbine of claim 1 wherein the at least one valve is able to switch the corresponding control jet between on and off states.

8. The hydraulic turbine of claim 1 the at least one nozzle head device is supported in liquid flow communication with conduit extending from the draft tube wall into an upper portion of the draft tube.

9. The hydraulic turbine of claim 1 wherein further comprising one or more pressure sensors in the draft for measuring the liquid pressure in the upper portion of the draft tube and relaying these measurements to an active control device which in turn controls movement of the nozzle head device in order to adjust the velocity of control jet of high velocity liquid.

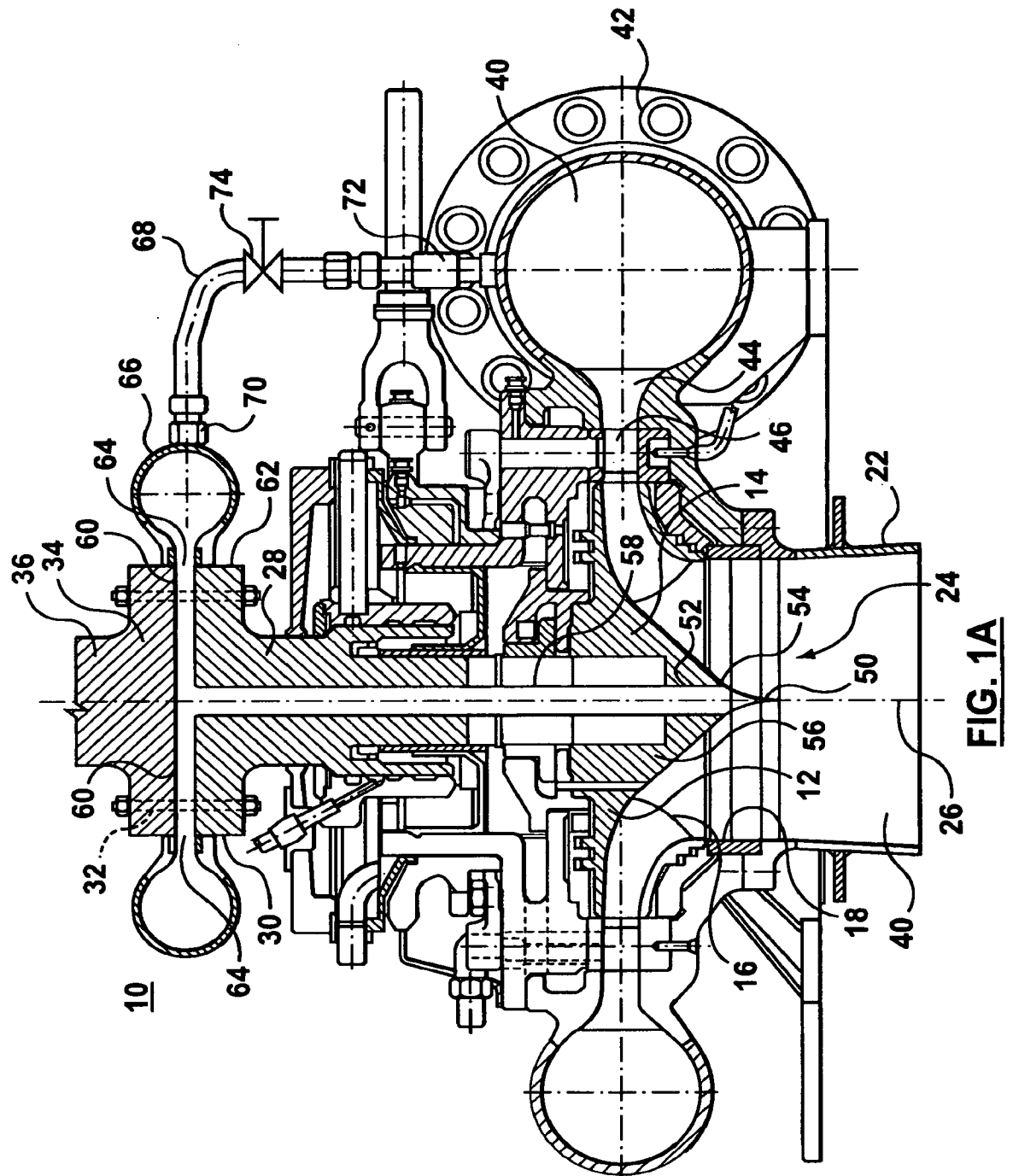
10. A method of controlling part load operation of a hydraulic turbine during part load conditions having a runner, a draft tube located downstream of the runner and a liquid passageway extending through the runner and the draft tube, the method comprising the step of injecting one or more control jets of high velocity liquid axially of the turbine, downstream of the turbine runner and into at least an upper portion of the draft tube.

11. The method of claim 10 comprising the step of locating the one or more control jets centrally of the runner prior to the step of injecting.

12. The method of claim 11 wherein during the step of injecting the one or more control jets of high velocity liquid, the one or more control jets are injected in one direction selected from the group consisting of along an axis of the turbine, parallel to

the turbine axis, converging on a focal point adjacent the upper portion of the draft tube lying on the turbine axis, and converging on a focal point adjacent the upper portion of the draft tube lying on a parallel axis adjacent to the turbine axis.

13. The method of claim 11 wherein the step of locating comprises locating the control jet or jets of high velocity liquid offset from a turbine axis.



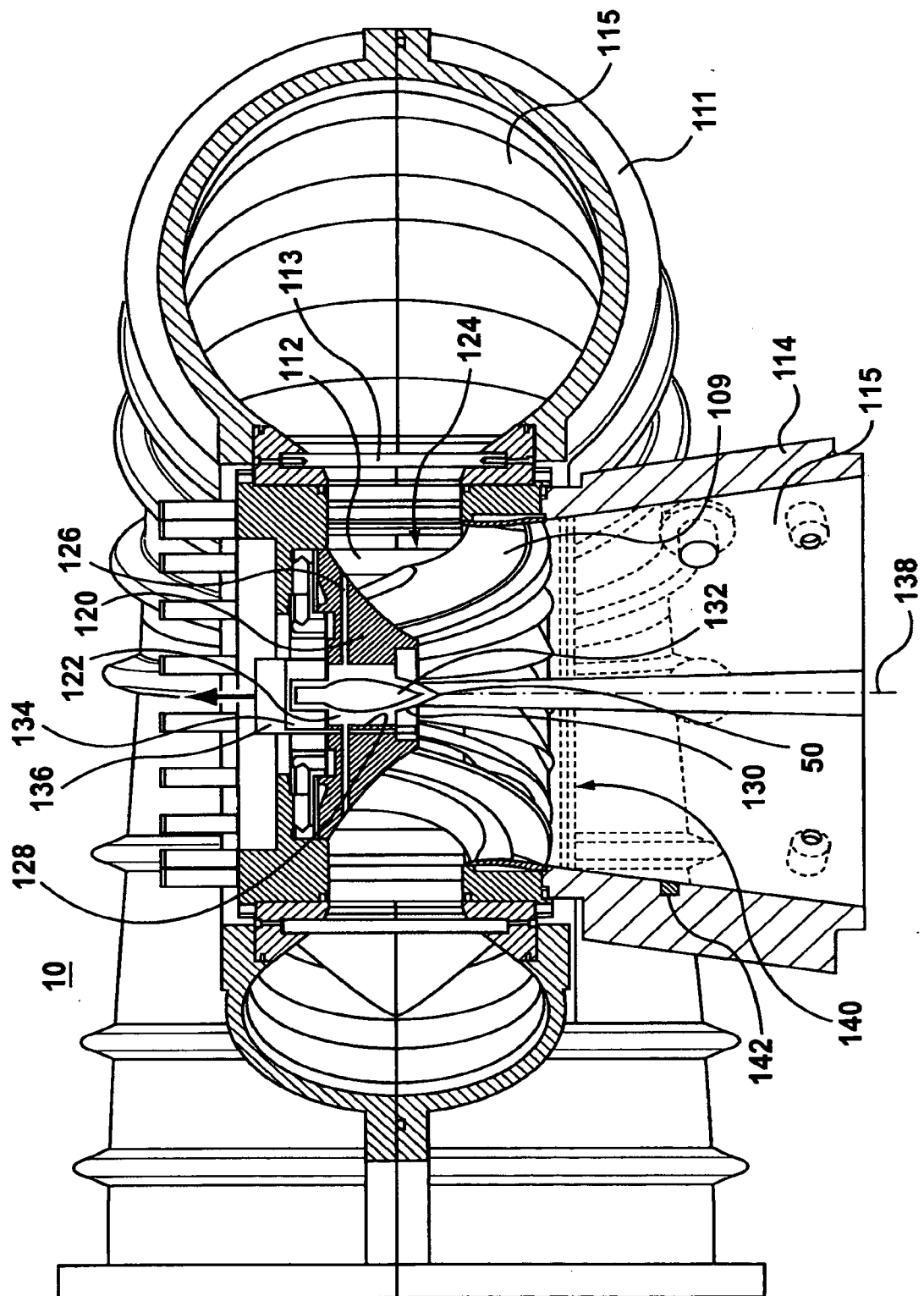


FIG. 1B

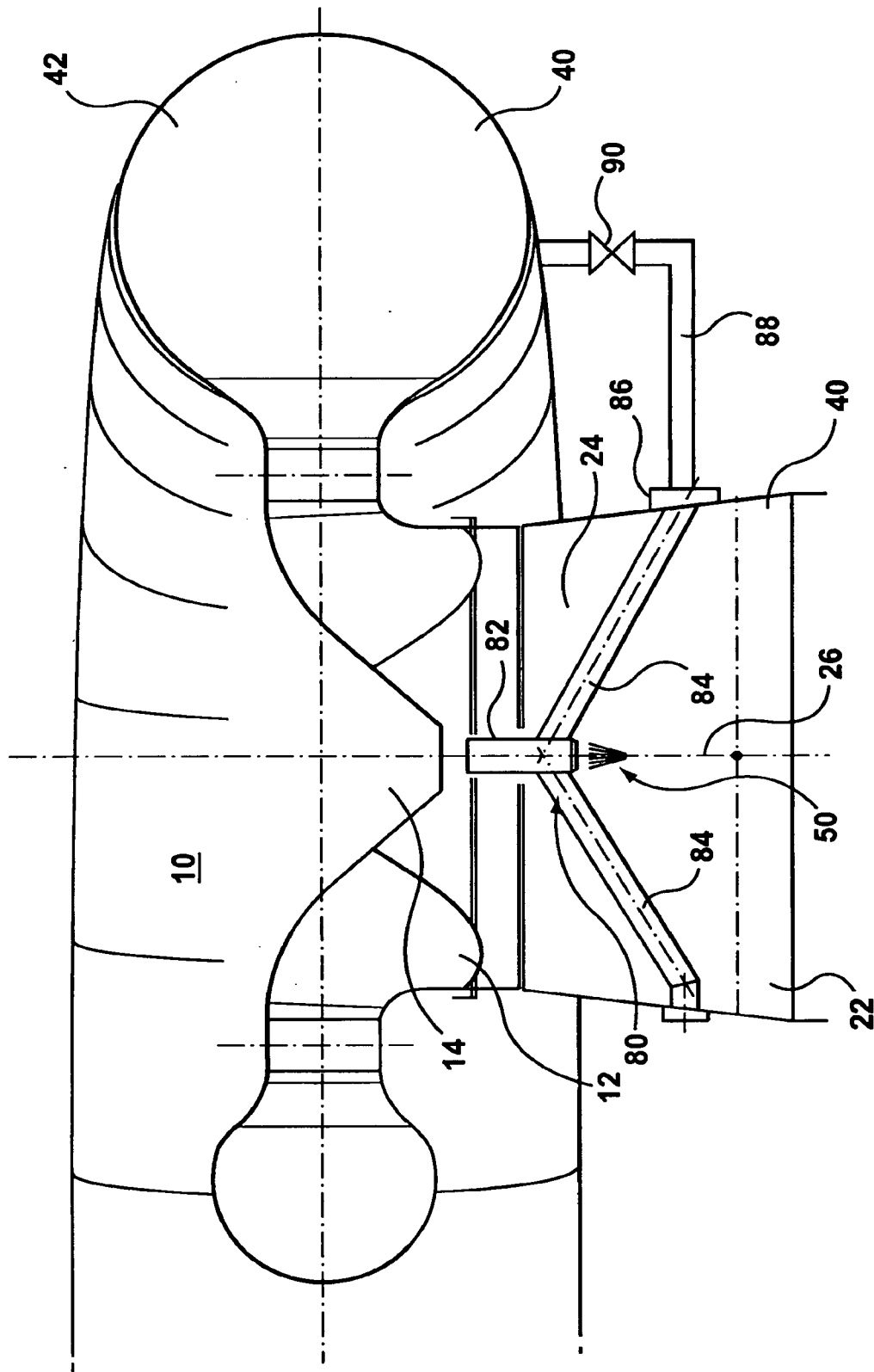


FIG. 2

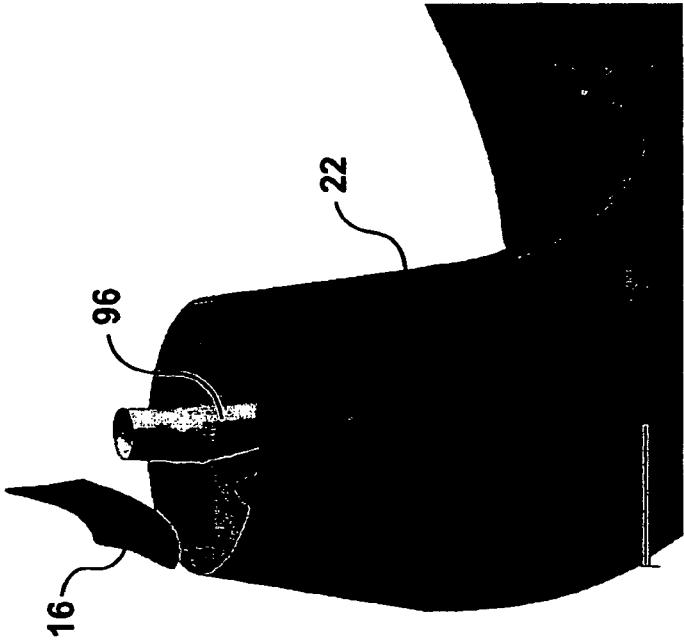


FIG. 3B

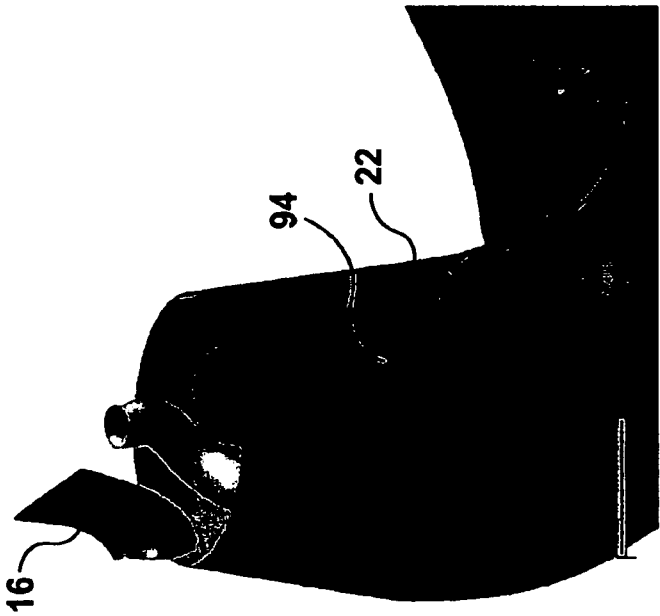


FIG. 3A

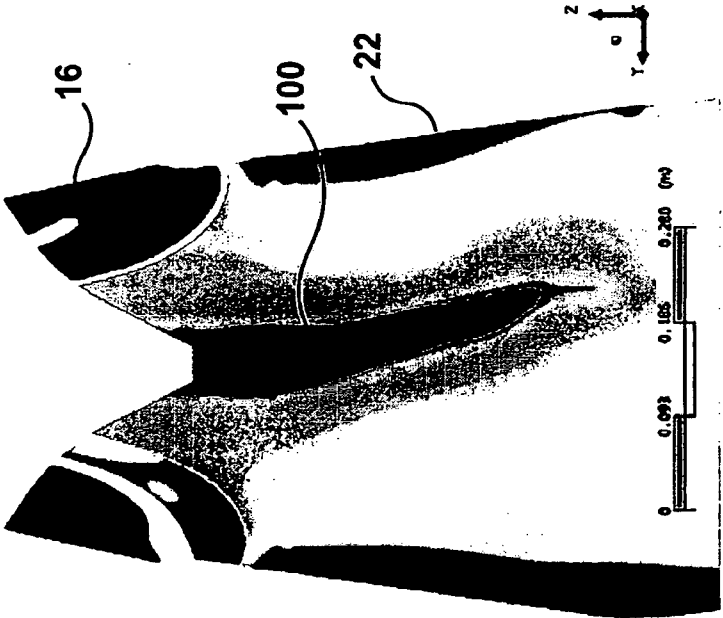


FIG. 4B

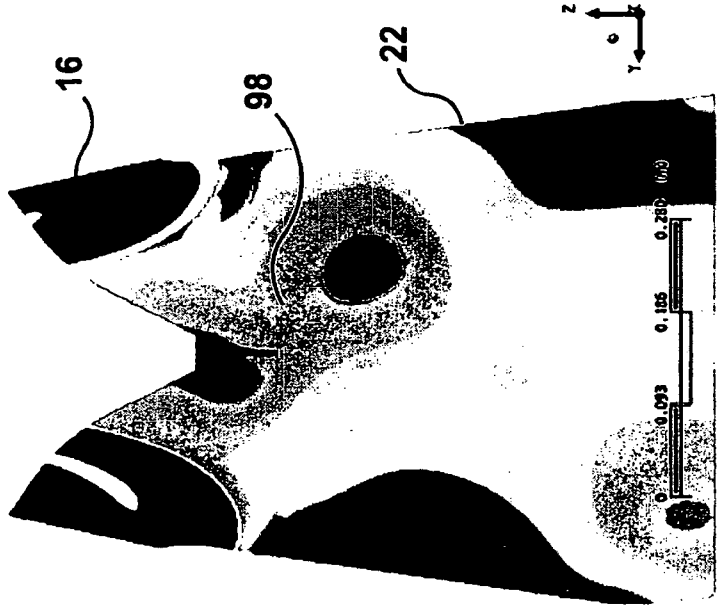


FIG. 4A

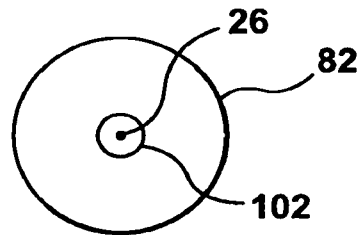


FIG. 5A

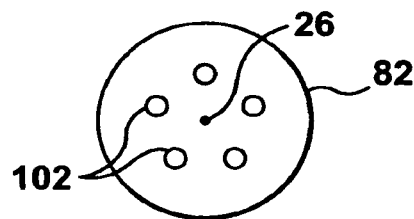


FIG. 5B

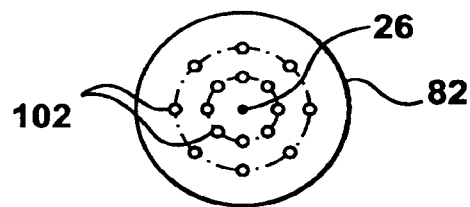


FIG. 5C

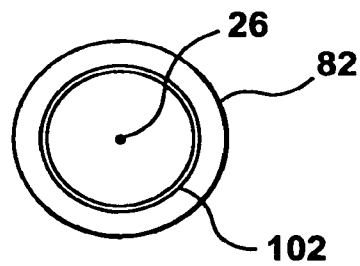


FIG. 5D

INTERNATIONAL SEARCH REPORT

International application No

PCT/US2007/004821

A. CLASSIFICATION OF SUBJECT MATTER

INV. F03B11/00

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)

F03B

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 practical, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	JP 57 008365 A (TOKYO SHIBAURA ELECTRIC CO) 16 January 1982 (1982-01-16) abstract; figure 3	1,2,6,7, 10
X	DE 73 27 606 U (SCHLEMMER, GUENTER, DIPL.-ING. DR.- ING., 8520 ERLANGEN) 14 October 1976 (1976-10-14) page 1, paragraph 1 page 2, last paragraph - page 3, paragraph 1 page 5, paragraph 1 - page 7, paragraph 1; claim 1; figure 1	1-4, 10-13
X	US 2005/165510 A1 (JENSEN RAYMOND V [US] ET AL JENSEN RAYMOND VERLE [US] ET AL) 28 July 2005 (2005-07-28) paragraphs [0003] - [0006], [0022] - [0024], [0029], [0032] - [0034]; figures	1,2,6,7, 9-13
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☒ Further documents are listed in the continuation of Box C.☒ See patent family annex.

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International application No

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