



- (51) International Patent Classification: Not classified
- (21) International Application Number:
PCT/ZA2015/000014
- (22) International Filing Date:
19 March 2015 (19.03.2015)
- (25) Filing Language: English
- (26) Publication Language: English
- (30) Priority Data:
2014/01193 20 March 2014 (20.03.2014) ZA
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- (81) Designated States (unless otherwise indicated, for every
kind of national protection available): AE, AG, AL, AM,

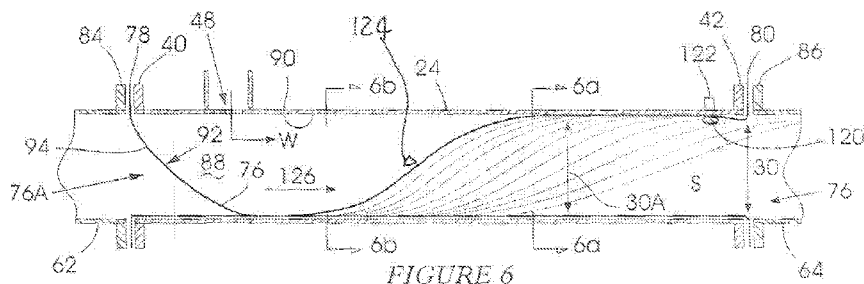
AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY,
BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM,
DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT,
HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KN, KP, KR,
KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG,
MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM,
PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC,
SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN,
TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

- (84) Designated States (unless otherwise indicated, for every
kind of regional protection available): ARIPO (BW, GH,
GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ,
TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU,
TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE,
DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU,
LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK,
SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ,
GW, KM, ML, MR, NE, SN, TD, TG).

Published:

— without international search report and to be republished
upon receipt of that report (Rule 48.2(g))

(54) Title: ENERGY RECOVERY



(57) Abstract: A unit for recovering energy from high pressure slurry which is fed, in a controlled way, into a flexible bladder, inside a pipe so that, as the bladder is filled with slurry, high pressure water is expelled from a volume between an inner surface of the pipe and the bladder, to drive a generator.

ENERGY RECOVERYBACKGROUND OF THE INVENTION

[0001] This invention relates to an energy recovery system.

[0002] The principles of the invention are suitable for use in the recovery of energy from a slurry source which has substantial potential energy due to the elevation of the source above a working point and, more particularly, is concerned with the conversion of such potential energy into another form of energy, e.g. into electrical energy, or with the transfer of such energy to another medium. The invention is described hereinafter with reference to the generation of electrical energy from a flow of slurry under pressure but this is exemplary only and is non-limiting.

[0003] The specification of international application No. PCT/ZA2009/000088 describes an energy generating system which makes use of two pressure vessels. Each vessel is cylindrical with hemispherical ends and is orientated so that its longitudinal axis is vertical. Nozzles are provided at upper and lower ends of the vessel.

[0004] Each vessel contains an elongate flexible bladder which is aligned with the longitudinal axis. The bladder, at an upper end, has an open neck which is sealingly engaged with the upper nozzle to define a first volume within the bladder, and a second volume between the bladder and an opposing inner surface of a wall of the vessel.

[0005] Slurry is fed under pressure from a downwardly-extending pipeline via a first slurry valve through the bottom nozzle to fill the second volume of one vessel. This

action forces the bladder inwardly around the longitudinal axis and, in so doing, water inside the bladder is displaced from the bladder through the upper nozzle. The displaced water can be directed to a suitable turbine which drives an electrical generator. When the vessel is full of slurry, the spent slurry is drained through a second slurry valve, to continue its downhill journey, and water refills the bladder gravitationally from a tank situated below the turbine.

[0006] While one vessel is being filled with water, and its slurry contents are draining out, the other vessel is being filled with slurry and displaces its water contents to an inlet of the turbine.

[0007] The process continues indefinitely in this way with the energy transfer changing from one pressure vessel to the other to produce a smooth discharge flow of water to the turbine.

[0008] During each period that slurry is filling a first vessel, the other vessel must be depressurised. The slurry flow rate must be increased, from a zero value, to drain all water from the first vessel. Thereafter the slurry flow rate must be progressively decreased to zero. The pressure in the first vessel is then raised to an operating value in readiness for the changeover of operation from the first vessel to the other vessel. A few seconds of waiting time, known as "overlap time", are then allowed before the switchover is implemented.

[0009] The various functions, which are essential for effective operation, are time consuming and place a limit on the ultimate flow rate of the system.

[0010] Apart from the aforementioned flow constraint, the system described in the international specification has some further drawbacks.

[0011] The vessels are expensive to manufacture. The hemispherical ends are complex and costly to form and the nozzles, at the upper and lower ends, are forgings which are machined. This is expensive and requires substantial production time. As the diameter of each vessel increases, cyclic hoop stresses which are generated during operation increase. The thickness of a wall of the vessel must therefore be increased to be able to handle the hoop stresses. An internal surface of the vessel which is in contact with the slurry requires a protective lining to resist abrasion.

[0012] Each vessel is vertically aligned so that slurry can flow into and out of the second volume through the lower nozzle. This results in a tall structure with a high centre of gravity which, in turn, calls for an extensive structural support framework as well as substantial civil foundations for stability, particularly in regions which are subject to seismic or similar events.

[0013] If the system is assembled in a building then sufficient clearance must be allowed above the structure for a crane which is used to assemble the vessels. The assemblies are large and, when transported, are regarded as abnormal loads and the relevant regulations then come into play.

[0014] High level service platforms and stairways must be provided, in conformance with safety requirements, so that the vessels and associated valves can be accessed for maintenance purposes. In addition the system must have a lifting device which can

extract and insert the bladders, and valve tubes through the upper nozzles, as service is required.

[0015] Overall a substantial amount of on-site work is required to install, commission and maintain the system. Stairways and service decks must be assembled on site as they are too bulky to be transported in an assembled condition.

[0016] An object of the present invention is to provide an energy recovery system which aims to address, at least partly, a number of the aforementioned aspects.

SUMMARY OF THE INVENTION

[0017] The invention provides in the first instance an energy transfer unit for transferring energy from a medium, from which energy is to be extracted, to a driven fluid, wherein the energy transfer unit includes:

- (a) an elongate tubular housing with an inner bore, a first end, an opposing second end and an inner surface,
- (b) an elongate flexible bladder of tubular form with an interior, an outer surface, an inlet, at one end of the bladder, to the interior through which the medium is directed into the interior, and an outlet, at an opposing end of the bladder, from the interior, through which the medium is directed out of the interior, the bladder being positioned inside the inner bore with the bladder in sealing engagement with the tubular housing at opposed ends of the bladder whereby the inlet is in communication with the first end of the tubular housing, the outlet is in communication with the second end of the tubular housing, and an operating

volume of variable size is formed between the outer surface of the bladder and the opposing inner surface of the tubular housing.

- (c) a port, for the driven fluid, on the tubular housing in communication with the operating volume,
- 5 (d) an inlet valve connected to the first end of the tubular housing,
- (e) an outlet valve connected to the second end of the tubular housing,
- (f) a first control valve for controlling the flow of the driven fluid through the port into the operating volume,
- (g) a second control valve for controlling the flow of the driven fluid from the operating volume through the port, and
- 10 (h) a monitoring arrangement for monitoring the flow of the driven fluid through the port.

[0018] The monitoring arrangement may comprise a bi-directional flow meter which provides a measurement of the volume of the driven fluid flowing into, or out of, the port.

15 To avoid incremental errors in the flow meter from accumulating over time a reading from the flow meter may be set to an absolute value, e.g. zero, regularly during operation of the unit.

[0019] In a preferred form of the invention the monitoring arrangement comprises one or more sensors which are responsive to movement of the bladder relative to one or more reference positions in or on the tubular housing. An advantage of this approach

20 lies in the fact that precise volume measurements of the driven fluid are not made. Switching of the operation of the unit is achieved by detecting positions of parts of the

bladder relative to reference positions on the housing. This technique eliminates the likelihood that incremental errors could occur.

[0020] The sensors may be of any suitable kind and for example may be capacitively based, comprise Hall effect sensors which are responsive to movement of magnets which are mounted to or which are otherwise movable by the bladder, conductive
5 sensors which respond to the movement of metallic components which are movable in conjunction with the bladder or the like. The invention is not limited in this respect.

[0021] The energy transfer unit may, in use, be provided in combination with a controller and the monitoring arrangement may be connected to the controller. The
10 controller may be responsive to signals from the monitoring arrangement which, in turn, are responsive to the volume of driven fluid which flows into the operating volume and the volume of driven fluid expelled from the operating volume.

[0022] The elongate tubular housing may be formed in any suitable way and preferably comprises a pipe, of an appropriate diameter, which complies with an appropriate
15 specification. Opposing first and second ends of the pipe may be flanged.

[0023] The port may be formed through a wall of the pipe.

[0024] The bladder, which is of tubular form, may be made from an appropriate material e.g. rubber.

[0025] Opposing ends of the bladder, i.e. at the inlet and the outlet, may be sealingly
20 engaged with the respective flanges at the first and second ends of the pipe.

[0026] The inlet valve may be adapted to allow the medium, from which energy is to be extracted, to move, under gravity action, into the interior of the bladder.

[0027] The outlet valve may be adapted to allow the medium from which energy has been extracted to move, under gravity action, into a discharge line.

5 [0028] The driven fluid may be of any suitable kind but, preferably, is water. Water flow into, and out of, the operating volume is monitored by the monitoring arrangement which measures the quantity (volume) of water which flows through into the volume, and out of the volume. This is important as the transfer of energy from the medium to the water is based on volume measurements, and not on time measurements in order to obtain a
10 controlled energy transfer sequence. If a meter is used a precise measurement of volume flow is obtained. However if use is made of one or more sensors which are responsive to movement of the bladder as it fills and empties with the medium then the volume measurement is less accurate for it is quite possible that the bladder does not move in the same way each time it is filled and emptied. However useful signals are
15 obtained which correspond effectively to situations in which the bladder is full or empty and if these signals are used to switch the cyclical operation of the unit errors which could accumulate through the effects of creep or the like are eliminated.

[0029] The invention extends, in the second instance, to energy recovery apparatus which includes three energy transfer units, each energy transfer unit being of the
20 aforementioned kind, wherein the three energy transfer units are mounted substantially parallel to one another on supporting structure. This supporting structure may have

outer dimensions which are substantially the same as the outer dimensions of a conventional shipping container.

[0030] With the supporting structure on a level surface a first end of each respective tubular housing may be elevated so that the tubular housing slopes downwardly over a length of the supporting structure towards the second end.

[0031] The respective inlet valves, for the medium, of the three energy transfer units and a first manifold may, in use, be positioned so that they lie outside the supporting structure. Similarly the respective outlet valves, for the medium, of the three energy transfer units and a second manifold may, in use, lie outside the supporting structure.

[0032] The use of three energy transfer units which are operated under the control of a suitable controller, enables the driven fluid to be displaced continuously through a turbine without meaningful pressure variations. Of importance is the fact that the flow rate of the driven fluid is approximately twice the flow rate of the system described in the aforementioned international patent application. In other words, by using three energy transfer units (each of the kind described herein) instead of two of the energy transfer units, up to a hundred percent increase in flow rate is achieved.

[0033] The flow rate of the driven fluid matches the rate at which the medium flows into the energy recovery apparatus. Typically, the medium is a slurry which flows under gravity action through a downhill pipeline. This is exemplary, and non-limiting.

[0034] The increased flow rate results from a controlled sequenced operation of the energy transfer units which are each able to work at a maximum rate for there is no

need to control the flow rate of a first energy transfer unit to allow for sufficient time within which a second energy transfer unit can be readied for operation, as is the case with the energy generating system in the international application. In the three unit arrangement of the present invention, the water (driven fluid) is displaced from a first energy transfer unit and, at the same time, a second energy transfer unit is prepared for discharge. Thereafter the operation is transferred from the first energy transfer unit to a third energy transfer unit and during water discharge from the third transfer unit, the preparation of the second energy transfer unit is completed, and the preparation of the first energy transfer unit for water discharge operation is commenced. The water discharge operation is then transferred to the second energy transfer unit, the preparation of the first energy transfer unit is completed and the preparation of the third energy transfer unit for water discharge operation is commenced.

[0035] The aforementioned process continues in this way, under the control of the controller, indefinitely. The cycle sequence is controlled by monitoring the volume of the driven fluid (water) which flows into, and subsequently is expelled from, each operating volume. Use is made of the monitoring arrangement to monitor these water volumes. It is however necessary to reset the count of a water meter (when used) to zero so that the volume of water which flows into a unit is controlled to be equal to the volume of water which flows out of a unit during each cycle of operation.

[0036] When a sensing arrangement is used to monitor the movement of the bladder the need to measure the volume of the water flowing into or out of the unit (in litres or gallons or other units) is eliminated and switching of the cyclical operation is effected simply and reliably by detecting movement of the bladder relative to one or more

predetermined positions on the tubular housing (the pipe). This approach practically eliminates the likelihood of incremental creep or overlap, due to inaccurate water measurements, causing a malfunction.

[0037] The control process is readily effected. As slurry flows into a bladder, water is expelled from the respective operating volume between the outer surface of the bladder and the inner surface of the pipe in which the bladder is located. The water which flows out is monitored by the respective monitoring arrangement. When the water flow stops this is indicative that the bladder has been filled with slurry. If a water meter is used then a count of the meter reading is reset to zero in the controller which, typically, is a PLC. When slurry is to be drained from a bladder water is introduced into the respective operating volume. Slurry flow is diverted from a first energy transfer unit to a second energy transfer unit. Before such diversion takes place, the pressure in the operating volume of the second energy transfer unit is increased to the prevailing operating pressure. Consequently when the slurry flow is diverted there is a substantially zero pressure difference between the pressure of the incoming slurry and the pressure of the water in the operating volume, and the diversion takes place without generating pressure spikes.

[0038] As indicated, in a preferred form of the invention the water flow meters are replaced by sensors. These are preferably spaced along the length of the pipe and bladder. If the energy transfer unit is being used with a medium such as a slurry and a driven fluid such as water then the difference between the specific gravities of these fluids remains fairly constant. This feature together with the fact that the tubular housing or pipe which contains the bladder is inclined to the horizontal (in use), means

that the bladder is displaced from the inner surface of the pipe, i.e. is deformed, in a predictable manner from one end of the pipe to the other. When the sensors are strategically positioned at spaced locations along the pipe they are capable of reporting the presence or absence of the bladder relative to the position of each respective sensor.

[0039] Preferably, the supporting structure used for the energy transfer units is in the nature of a conventional container. This facilitates assembly of the energy recovery apparatus, its transport to a usage site and, at the usage site, installation, commissioning and maintenance of the apparatus. Site preparation requirements are minimised. Typically, at an installation site, the first and the second manifolds and the attendant valves, which are separately transported, e.g. in a second container, are connected to the energy transfer units. The supporting structure (container) used for the energy transfer units can have mounted to it gantries or jibs to facilitate assembly processes on site.

[0040] In the aforementioned arrangement each of the energy transfer units is thus fairly close to the ground.

[0041] A modular water tank can be placed on top of the container structure. The water tank may include a pipe from its base, which drains water directly into the second (return) manifold.

[0042] The turbine may be positioned above the water tank, and water exiting the turbine may be directed into the water tank.

BRIEF DESCRIPTION OF THE DRAWINGS

[0043] The invention is further described by way of example with reference to the accompanying drawings in which :

Figure 1 is a view in perspective of three energy transfer units, included in energy recovery apparatus according to the invention, mounted to support structure which is in the form of a conventional container which has a standard length, height and width;

Figure 2 is a view in elevation of the arrangement shown in Figure 1;

Figure 3 is a plan view of the arrangement in Figure 1;

Figure 4 is an end view of the arrangement, in the direction of an arrow marked 4 in Figure 3;

Figure 5 illustrates in perspective a bladder used in an energy transfer unit;

Figure 6 is a schematic view from one side and in cross-section depicting the mounting of the bladder of Figure 5 to a pipe;

Figures 6A and 6B are cross sectional views of the pipe and bladder taken on the lines 6a-6a and 6b-6b respectively in Figure 6 showing different configurations as the bladder collapses;

Figure 6C is similar to Figure 6 but illustrating a preferred form of the sensor included in the bladder,

Figure 7 includes four views in cross section of an energy transfer unit in different stages of operation,

Figure 8 is a view from one side of the energy transfer units (i.e. similar to what is shown in Figure 2) with first and second manifolds and inlet and outlet valves connected to the energy transfer units;

Figure 9 is a side view on an enlarged scale and in section of part of the first manifold and an inlet valve shown in Figure 8;

Figure 10 is similar to Figure 9, but showing a portion of the second manifold and an outlet valve;

Figure 11 includes four images, namely Figure 11A which shows a slurry-in manifold, Figure 11B which shows a water-in manifold; Figure 11C which shows a water-out manifold; and Figure 11D which shows a slurry-out manifold; and

Figure 12 has two views which illustrate in plan, and from one side, respectively, an assembled energy transfer unit.

DESCRIPTION OF PREFERRED EMBODIMENT

[0044] Figures 1 to 4 are different views of energy recovery apparatus 8 which includes three energy transfer units 10, 12 and 14 respectively which are mounted to supporting structure 18.

[0045] The supporting structure is shown in skeletal form. Typically the supporting structure is embodied in, or constituted by, a conventional transport container i.e. the structure 18 has a length L, a height H and a width W (Figure 1) which conform to the dimensions of a conventional container. Sides of the supporting structure are not closed — this facilitates access to equipment mounted to the structure.

[0046] The construction of the unit 14 only is described hereinafter. The units 10 and 12 are similar to the unit 14.

[0047] The unit 14 includes an elongate tubular housing comprising a pipe 24 which is made to a suitable specification and which has a length 26 and a diameter 30. The pipe

24 has a first end 34 and an opposing second end 36. Each end is provided with a respective flange 40, 42.

[0048] Near the first end 34 (Figure 2) the pipe 24 is formed with connecting structure 46 which includes an inlet port 48. A water supply pipe 50 is connected to the port 48. A bi-directional water meter 52 is connected in line to the pipe 50. At an end remote from the port 48 the pipe 50 is connected to a control valve 54 which is coupled to a water – out manifold 54A and to a control valve 56 which is coupled to a water- in manifold 56A.

[0049] The pipe 24 slopes downwardly, from the left to the right in Figure 2, when the supporting structure 18 is on level ground.

[0050] The energy transfer units 10, 12, 14 are assembled under factory conditions. The supporting structure 18 and pumps, associated with the energy transfer units, can then be shipped using conventional container transport techniques to an installation site.

[0051] A second container, not shown, houses a controller 60 such as a PLC, a hydraulic power pack for valve actuation, an air-conditioner, a priming pump set, a store and a site office, three inlet valves 62 (Figure 9) and three outlet valves 64 (Figure 10) (one valve 62 and one valve 64 for each respective energy transfer unit), a slurry-in manifold 66 (Figure 11A), and a slurry-out manifold 68 (Figure 11D). The second container is also shipped, with its contents secure inside, to the installation site. At this site use can be made of jibs or cranes (not shown) which are fixed to the first container

(Figure 8), i.e. to the supporting structure 18, to assist in mounting the manifolds and valves to the respective ends of the pipes 24 of the three units 10, 12, 14.

[0052] Figure 6 illustrates in cross-section, and from one side, the pipe 24. Positioned inside the pipe is a bladder 76 which is made from a flexible material such as rubber.

5 The bladder is also shown in Figure 5. The bladder is of elongate tubular form and has flange formations 78 and 80 at opposed ends. These flange formations respectively overlie faces of the flanges 40 and 42 and, in use, are clamped between a mating flange 84 of the respective inlet valve 62 and a mating flange 86 of the respective outlet valve 64, respectively. The bladder has a nominal diameter 30A which is the same as
10 the diameter 30. A first, open end 76A of the bladder 76 is in direct communication with the first end of the pipe 24, and an opposing, second, open end 76B of the bladder is in direct communication with the second end of the pipe. An operating volume 88, of variable size, is formed between an inner surface 90 of the pipe 24 and an opposing outer surface 92 of the bladder 76. The inlet port 48 is in direct communication with the
15 operating volume 88.

[0053] Figure 9 shows from one side and in cross-section a portion of the inlet valve 62 and the pipe 24. The port 48, which is an opening in a side wall of the pipe 24, is crossed by a grid structure 96 which, in use, prevents the bladder 76 from being forced into the water pipe 50, when the bladder is filled with slurry S. A rubber portion of the
20 bladder which opposes the grid structure may be reinforced e.g. with a flexible material to prevent that portion of the bladder from being extruded through the grid when the bladder is internally pressurised.

[0054] The first end 34 of the pipe 24 is connected via tubular structure 98 to the respective inlet valve 62 and the second end 36 is connected by means of tubular structure 102 to the respective outlet valve 64, see Figure 10.

[0055] The three inlet valves 62 associated with the respective energy transfer units are connected at their inlets to the slurry-in manifold 66 shown in Figure 11A. The three outlet valves 64 associated with the respective energy transfer units are connected at their respective outlets to the slurry-out manifold 68 shown in Figure 11D. This manifold is connected to a discharge line.

[0056] The slurry-in manifold 66 is connected to a downhill slurry pipeline.

[0057] The outlets from the control valves 54 of the three energy transfer units are connected to the water-out manifold 54A shown in Figure 11B. The inlets to the control valves 56 of the three energy transfer units are connected to the water-in manifold 56A shown in Figure 11C.

[0058] The water meters 52 provide data on flow of the water W, to the controller 60. The control valves 54 and 56, as well as the inlet and outlet valves 62 and 64, are responsive to signals from the controller 60 which functions in accordance with a proprietary algorithm to regulate the operation of each energy transfer unit.

[0059] Assume that the energy recovery apparatus 8 is used to recover energy from high pressure slurry S flowing in a downhill slurry pipeline. In cyclical operation the high pressure slurry S enters each energy transfer unit sequentially. Each unit, in turn transfers the energy in the slurry S, via the respective bladder interface, to the water W within the unit, thereby causing the water to be directed, at the same rate and pressure

as the incoming slurry, to a turbine. Water W is discharged from the turbine into an elevated tank above the recovery apparatus 8. Water drains from the elevated tank to fill each energy transfer unit in sequence and in readiness for the next cycle. While the water is draining from the elevated tank into each respective energy transfer unit, the slurry, from which energy has been extracted, drains out of each relevant energy transfer unit into a downstream length of the pipeline.

[0060] Referring to Figure 8 the slurry S is fed under pressure from the pipeline, through the respective inlet valve 62 into the bladder of the energy transfer unit 14. Water flows from the operating volume of that energy transfer unit via the port 48 into the line 50 and, from there, through the control valve 54 to the turbine. This water is expelled by the pressure exerted by the slurry as the slurry flows into the interior of the bladder. Once the bladder is filled with slurry, the size of the respective operating volume 88, for practical purposes, is zero. The volume of water flowing out of the operating volume 88 is monitored by the corresponding meter 52 and is recorded in the controller 60.

[0061] While the slurry S is flowing into the bladder of the energy transfer unit 14, water W from the water tank fills the operating volume 88 of the energy transfer unit 10, as the slurry drains out of that unit, through the respective outlet valve 64.

[0062] The quantity (volume) of water W flowing into the operating volume 88 of the unit 10 is measured by the water meter and is controlled to be equal to the quantity previously expelled due to the action of the bladder, as measured by the meter. The size of the operating volume 88 of the energy transfer unit 14 is decreased. The volume of the bladder is increased. Water W is thus expelled from the operating volume 88

into the water-out manifold 54A through the respective control valve 54, and into the turbine.

[0063] While the energy transfer unit 14 is active the second energy transfer unit 12 is readied to ensure that the appropriate water volume is charged into the respective operating volume 88, and that the bladder of the unit 14 contains no slurry. The pressure in the second unit 12 is raised to the system operating pressure. The pressure prevailing in the operating volume 88 of the second energy transfer unit 12 is controlled via the controller 60 and is set to be equal to the pressure of the water available to the turbine. Effectively, the water in this operating volume is brought to an operating pressure by slightly opening the corresponding control valve 54. This is done at a time which is shortly before switch-over takes place from the slurry feed pipe. As the water is incompressible the amount of water which must be introduced into the operating volume, to raise the pressure therein to the desired level, is minimal.

[0064] Once the energy transfer unit 14 has completed its energy transfer cycle, as determined and controlled by the measurements from the water meter (applied to the controller 60), the water meter count held in the controller 60 and related to the unit 14 is set to zero. At this point slurry flow is diverted into the second energy transfer unit 12. Water W is discharged from the operating volume 88 of the second energy transfer unit 12 via the corresponding water-out control valve 54, into the water-out manifold 54A shown in Figure 11B. The operation is thus diverted smoothly from the third energy transfer unit 14 to the second energy transfer unit 12. This is done without producing any pressure spikes and without interrupting the slurry flow from the pipeline. The

quantity (volume) of water which goes into the second energy transfer unit 12 is monitored, as before, by the appropriate bi-directional water meter 52.

[0065] Each time water is driven or expelled from an energy transfer unit, the volume of water is metered and controlled to be equal to the volume of water which previously flowed into the energy transfer unit. This approach helps to avoid adverse effects which could be produced by incremental creep.

[0066] During the period in which the energy transfer unit 14 is being operated, and when switching takes place from the energy transfer unit 14 to the energy transfer unit 12, the energy transfer unit 10 is readied for operation. Consequently, on a continuous basis, when a first energy transfer unit is being filled with slurry S and is discharging water W, a second energy transfer unit is discharging its slurry S and is being filled with water W. During the same period the operating pressure in a third energy transfer unit is being "balanced" in readiness for the next switchover. Therefore smooth switching between cycles can be accomplished with ease and without producing pressure spikes or flow interruptions.

[0067] The bladder 76, at what in use is a lower end, has one or more metallic inserts 120, see for example Figure 5, which are embedded into the rubber or otherwise attached to the rubber from which the bladder is made. The pipe 24 in which the bladder is inserted has a sensor 122 (Figure 6) or a number of sensors which are responsive to the presence or absence of the inserts.

[0068] Figure 6 illustrates from one side and somewhat schematically how a bladder 76 is deformed when water W is introduced into the operating volume 88. Figure 6A is a

cross sectional view of the pipe and the bladder taken on a line 6a-6a in Figure 6 and Figure 6B is similar to Figure 6A but taken on a line 6b-6b in Figure 6.

[0069] Initially the bladder in a region which directly opposes an exit aperture from the port 48 is collapsed and one half portion 76X of the bladder is urged into close contact with an opposing half portion 76Y of the bladder – see Figure 6B.

[0070] As the water W continues to flow into the volume 88 the bladder is gradually collapsed over its length with a sloping surface 124 of the bladder which faces the volume 88 being moved continuously to the right in Figure 6 in the direction of an arrow 126. The collapsing of the bladder is stopped, i.e. the water flow into the volume 88 is interrupted, when the metal insert 120 moves away from the sensor 122. If the bladder were to be compressed or collapsed beyond this point then it is possible that the bladder would be damaged. The metal insert and the sensor thus act as a backup in that if the insert is moved away from the sensor this is indicative that an unallowable condition has arisen and, when this occurs, operation of the energy recovery apparatus is immediately stopped to prevent the respective bladder from being damaged.

[0071] The position of the bladder relative to the pipe is reliably indicated by means of the interaction of the metal insert 120 with the sensor 122. However as is described hereinafter the use of inserts and sensors can be further developed to provide an alternative, preferred embodiment of the invention.

[0072] Referring to Figure 6C a number of sensors A, B, C are strategically positioned on the pipe to sense the position of the bladder relative to defined locations on the pipe. A first sensor A is positioned at one end of the pipe, a second sensor B is positioned at

an opposing end of the pipe and a third sensor C is positioned at an intermediate location on the pipe. Each sensor effectively gives an on/off output and this is indicative of the position of the bladder relative to the pipe in an area or location adjacent the sensor. The signals which are output by the respective sensors associated with one
5 pipe are used as parameters to control the operation of the relevant valves on an adjacent pipe, and the internal pressurisation of that pipe. Similar sensors on a second pipe are used to control corresponding events on a third pipe and in turn, similar sensors on a third pipe, via the controller 60, control similar operations on the first pipe.

[0073] Conveniently, in one form of the invention, each sensor comprises an inductive
10 coil which establishes an electromagnetic field in a region inside the pipe adjacent the sensor. Attached to the bladder for each sensor is a respective metallic insert A1, B1, and C1, which, upon movement of the bladder, is moved into the electromagnetic field or out of the electromagnetic field. This movement influences the strength of the electromagnetic field and provides a reliable means for detecting when the bladder is
15 expanded or collapsed relative to the location of the sensor. A convenient metal insert (A1, B1, C1) is formed by a flexible metallic patch e.g. one or more flexible metal wires embedded in a layer of rubber. The wires are orientated so that they do not interfere with the expansion of the bladder as it is pressurised nor with the collapsing of the bladder as it is externally pressurised. The rubber of the insert is bonded to the rubber
20 of the bladder.

[0074] A significant benefit related to the use of the sensors lies in the fact that the sensors are reliable and relatively cheap. More particularly, they eliminate the need for the bi-directional water meters 52 which are expensive components and which require

resetting to zero at a predetermined position during each cycle of operation of the energy recovery unit.

[0075] It is preferred to make use of the metal inserts and the sensors which are responsive to the presence or absence of the metal inserts. In general terms though any appropriate sensor which is responsive to the position of the bladder relative to a defined location on the pipe which houses the bladder can be employed. It is observed in this respect that the bladder, when it is inflated and when it is deflated moves, each time, substantially in the same way – a characteristic which is particularly pronounced when there is a reasonable density (specific gravity) difference between the driven fluid (the water), and the medium which constitutes an energy source (i.e. the slurry).

[0076] Figure 7 has four cross sectional views of an energy transfer unit illustrating how its bladder is deformed as slurry S flows into the unit.

[0077] Figure 7A shows an energy transfer unit 10 with the operating volume 88 fully inflated with water W. The respective inlet valve 62, not shown, is closed and slurry S cannot enter the bladder. The slurry outlet valve 64 associated with the unit 10 is open and, as the volume 88 is filled with water W, slurry S is expelled from the bladder, to the left in Figure 7A.

[0078] Thereafter, as is shown in Figure 7B, the outlet valve 64 is closed and the inlet valve 62 is opened. Water can flow from the volume 88 through the port 48. The pipe 24 slopes, in this example, from the right side downwardly to the left side. The slurry S is more dense than the water W and consequently the bladder 76 is filled from the left side with a sloping side 76S of the bladder being moved to the right as is indicated by

means of an arrow M. As the bladder is inflated with the slurry water flows through the port 48.

[0079] Figure 7C shows that the sloping side 76S is close to the port 48 while, in Figure 7D, the bladder is filled with slurry and substantially all of the water which was in the volume 88 has been expelled through the port 48.

[0080] The invention holds a number of benefits. The construction of the energy recovery apparatus is simplified compared, for example, to the system described in the aforementioned international application. On-site requirements are reduced primarily because construction and assembly take place under factory conditions. Through the use of three energy transfer units the flow rate, compared to the flow rate in the system in the aforementioned international application, is effectively doubled.

[0081] Further benefits include the following, some of which have already been referred to:

- As the container to which the components of the energy recovery apparatus are mounted, and which is used for transport purposes, is, for practical purposes a conventional shipping container, the shipping and transport thereof can be accomplished on a worldwide basis using normalised techniques.
- Within each energy transfer unit the respective bladder is protected against on-stream slurry or water pressure losses. By way of contrast in the system described in the international application which has been referred to, if there is a downstream slurry pressure loss, then at least one of the bladders, which is filled

with water, would, inevitably, be destroyed in that it would not be surrounded and supported by slurry inside the pressure vessel.

- Maintenance of the components in the apparatus of the current invention can be effected at ground level.

CLAIMS

1. An energy transfer unit (10, 12, 14) for transferring energy from a medium, from which energy is to be extracted, to a driven fluid, wherein the energy transfer unit includes:
 - 5 (a) an elongate tubular housing (24) with an inner bore, a first end (34), an opposing second end (36) and an inner surface,
 - (b) an elongate flexible bladder (76) of tubular form with an interior (88), an outer surface (92), an inlet (76A), at one end of the bladder, to the interior (88) through which the medium is directed into the interior (88), and an outlet (76B), at an
10 opposing end of the bladder (76), from the interior (88), through which the medium is directed out of the interior (88), the bladder (76) being positioned inside the inner bore with the bladder (76) in sealing engagement with the tubular housing (24) at opposed ends of the bladder (76) whereby the inlet (76A) is in communication with the first end (34) of the tubular housing (24), the outlet (76B) is in communication with the second end (36) of the tubular housing (24), and an
15 operating volume (88) of variable size is formed between the outer surface (92) of the bladder (76) and the opposing inner surface (92) of the tubular housing (24),
 - (c) a port (48), for the driven fluid, on the tubular housing in communication with the
20 operating volume (88),
 - (d) an inlet valve (62) connected to the first end (34) of the tubular housing (24),
 - (e) an outlet valve (64) connected to the second end (36) of the tubular housing (24),
 - (f) a first control valve (56) for controlling the flow of the driven fluid through the port (48) into the operating volume (88),

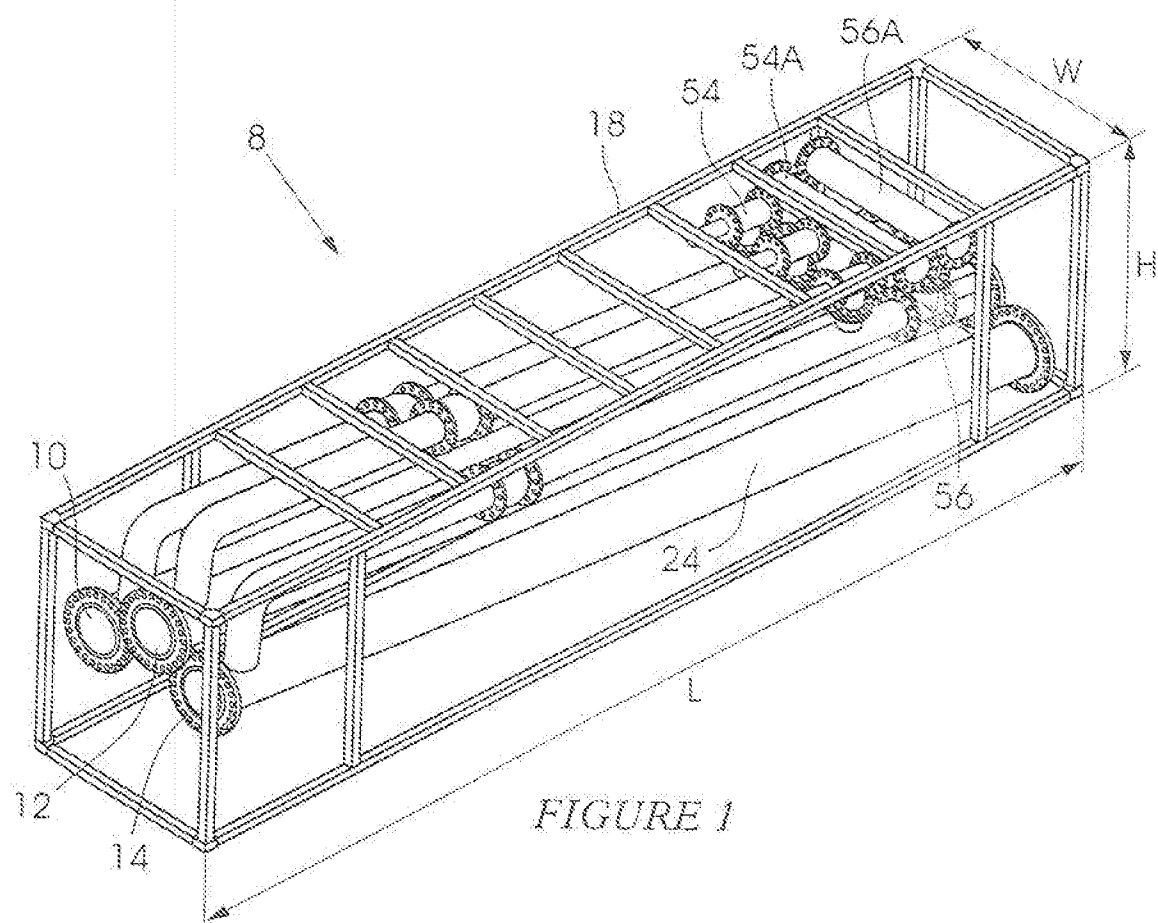
- (g) a second control valve (54) for controlling the flow of the driven fluid from the operating volume through the port (48), and
- (h) a monitoring arrangement (60) for monitoring the flow of the driven fluid through the port.

- 5 2. An energy transfer unit (10, 12, 14) according to claim 1 wherein the monitoring arrangement (60) includes at least one of the following: a bi-directional flow meter (52); and at least one sensor (122) which is responsive to movement of the bladder (76) relative to a predetermined position in or on the tubular housing (24).
- 10 3. An energy transfer unit (10, 12, 14) according to claim 1 wherein the monitoring arrangement (60) includes a plurality of sensors (A, B, C) at respective spaced apart locations on the tubular housing (24) and wherein each sensor is responsive to movement of the bladder (76) relative to the respective location on the tubular housing (24) for such sensor.
- 15 4. An energy transfer unit (10, 12, 14) according to claim 1 wherein the inlet valve (62) is used to control flow of the medium into the bladder (76) and wherein the outlet valve (64) is used to control flow of the medium from the bladder (76).
- 20 5. Energy recovery apparatus (8) which includes three energy transfer units (10, 12, 14), each energy transfer unit being according to claim 1, the three energy transfer units (10, 12, 14), being mounted substantially parallel to one another on supporting structure (18) and wherein, with the supporting structure (18) on a level surface, a first end of each respective tubular housing (24) is elevated so

that the tubular housing (24) slopes downwardly over a length of the supporting structure (18) towards a second end of the tubular housing (24).

6. Energy recovery apparatus (8) according to claim 5 wherein the supporting structure conforms in outer dimensions to the dimensions of a standard shipping container.

7. Energy recovery apparatus according to claim 5 or 6 which includes a first manifold (54A) and a second manifold (56A) and wherein the respective inlet valves (62) of the three energy transfer units (10, 12, 14), and the first manifold (54A) are, in use, positioned so that they lie outside the supporting structure (18) and the respective outlet valves (64) of the three energy transfer units (10, 12, 14), and the second manifold (56A) are in use positioned to lie outside the supporting structure (18).



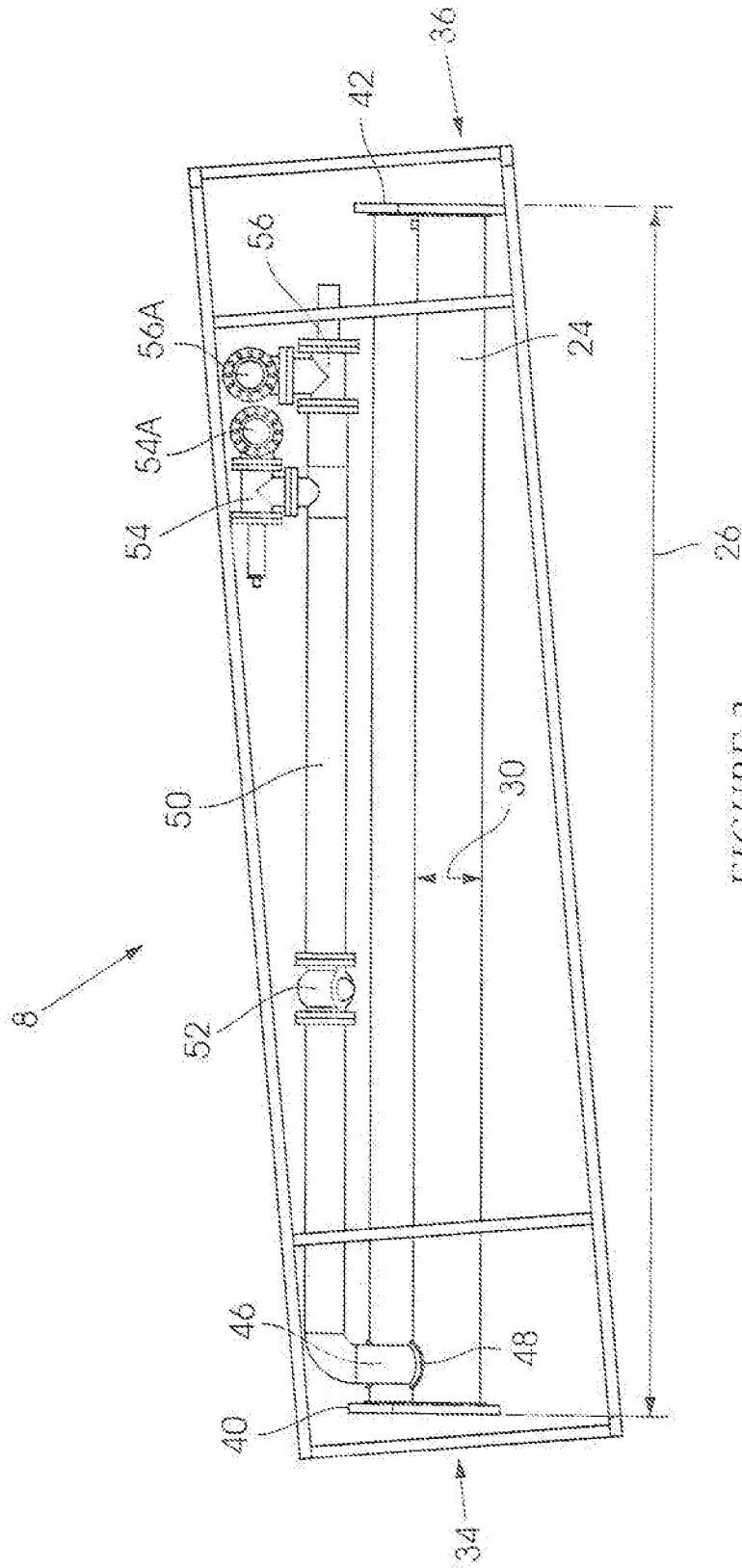


FIGURE 2

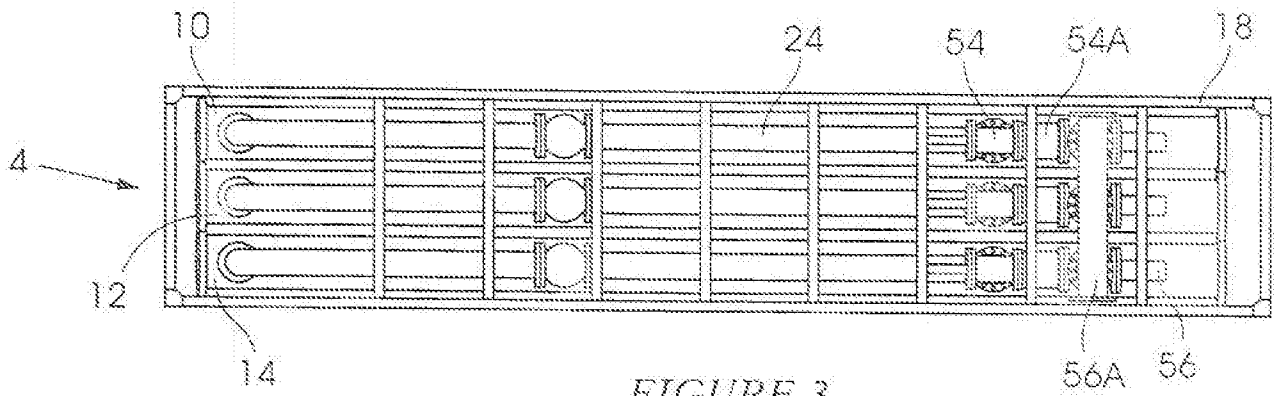


FIGURE 3

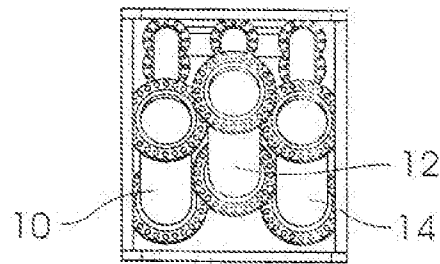


FIGURE 4

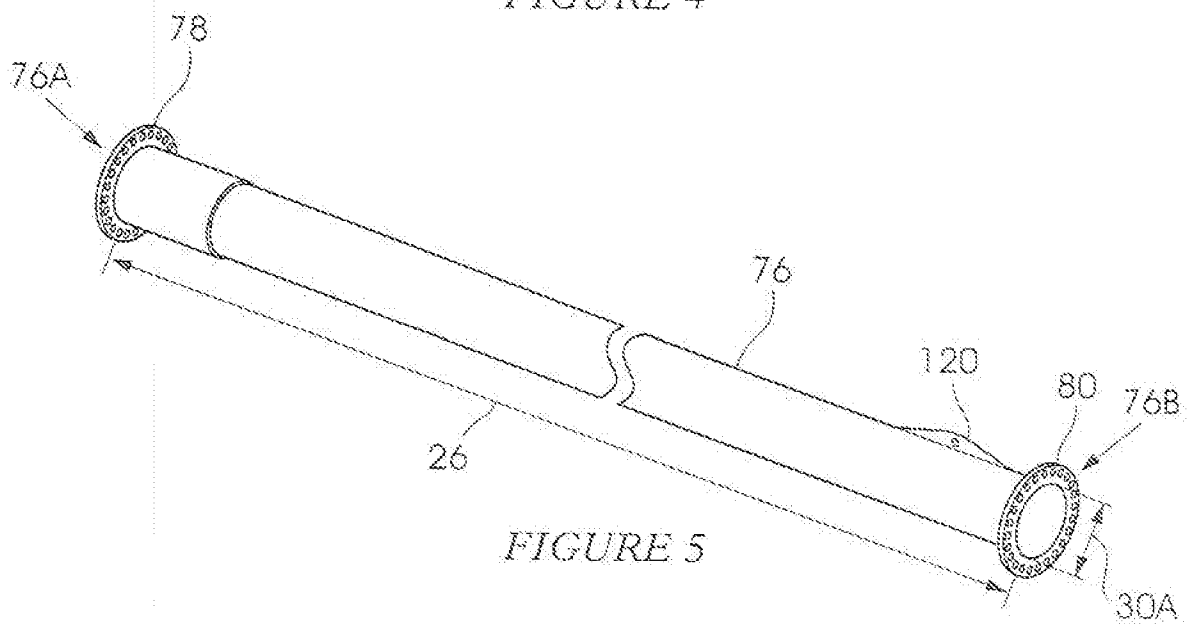


FIGURE 5

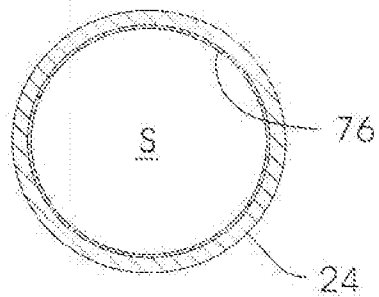
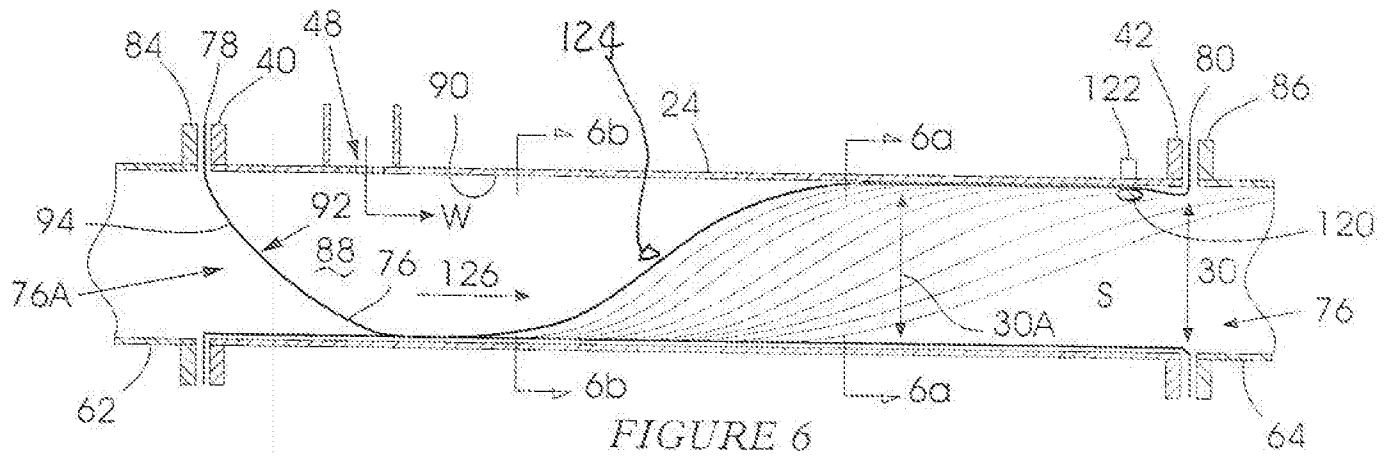


FIGURE 6A

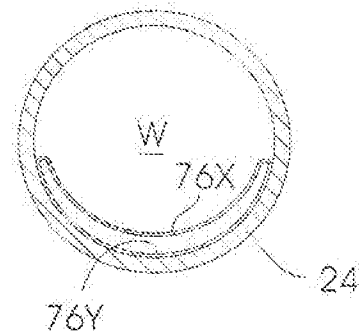
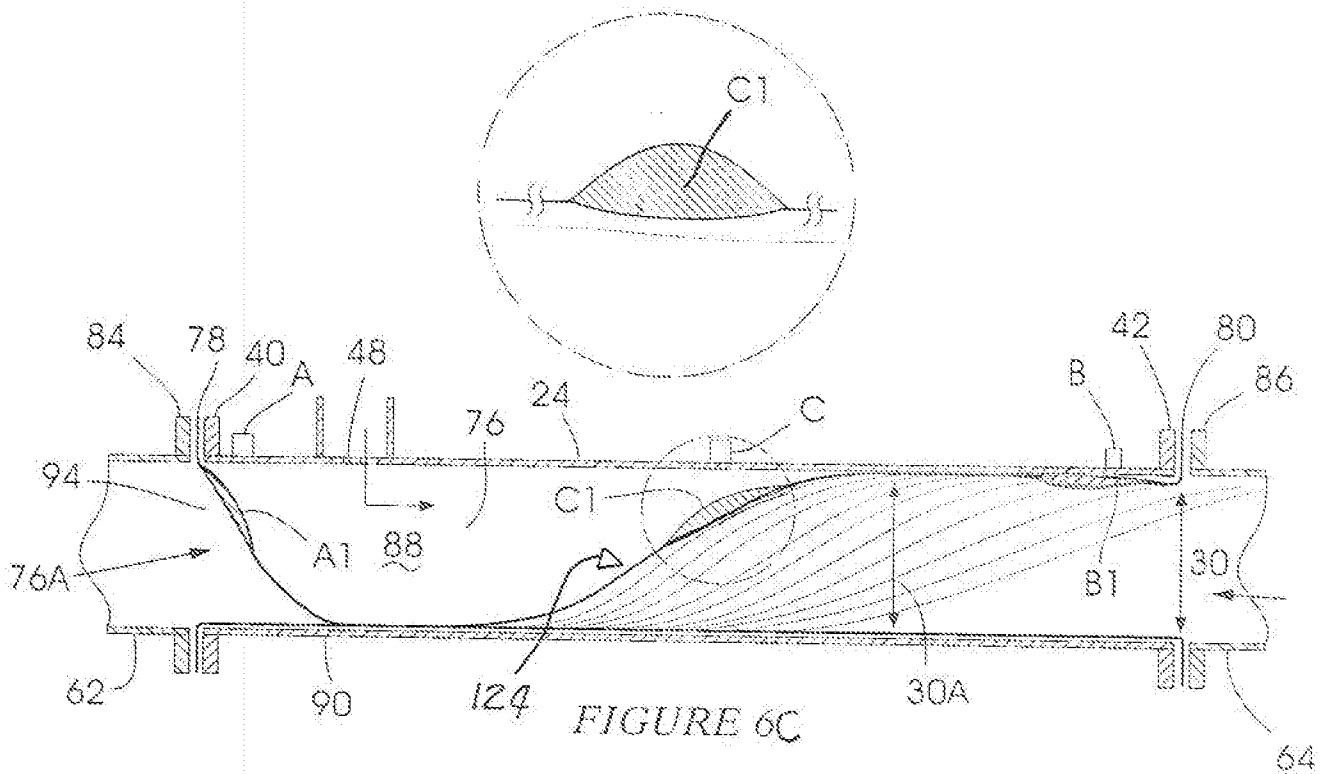


FIGURE 68



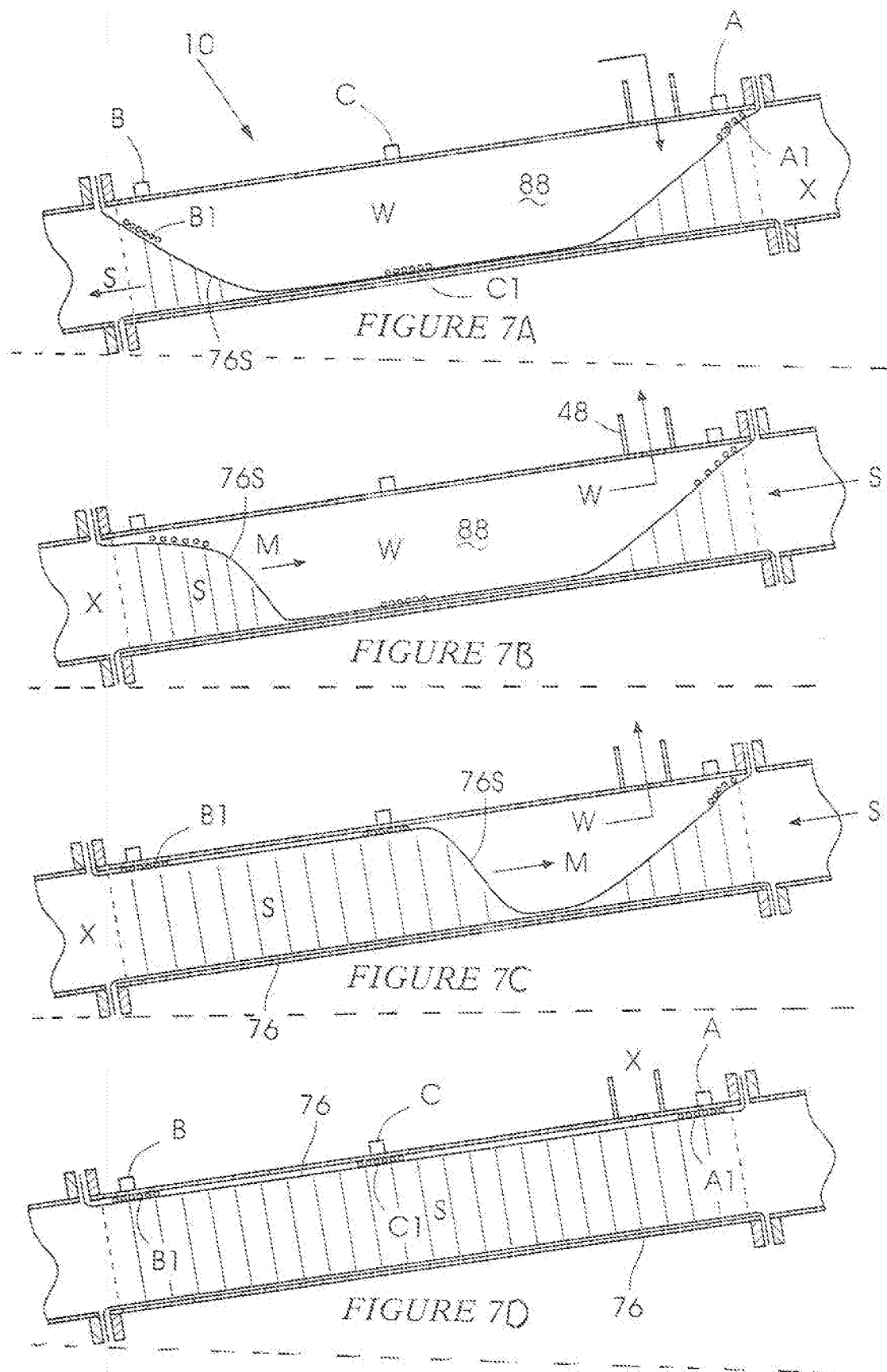
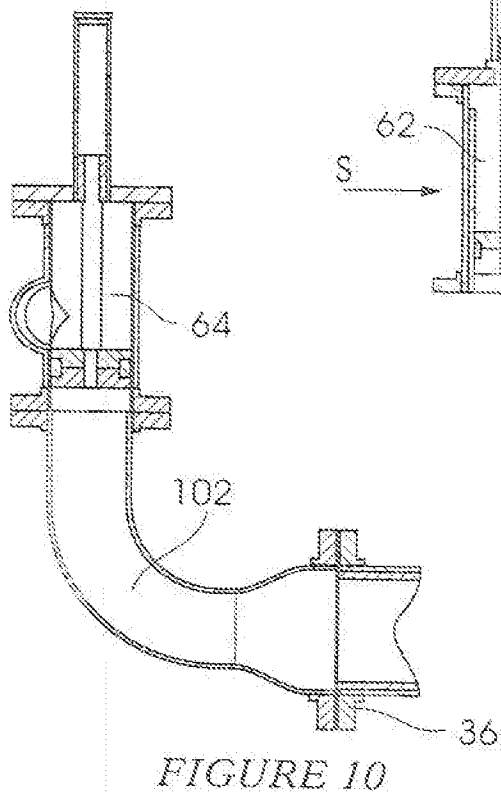
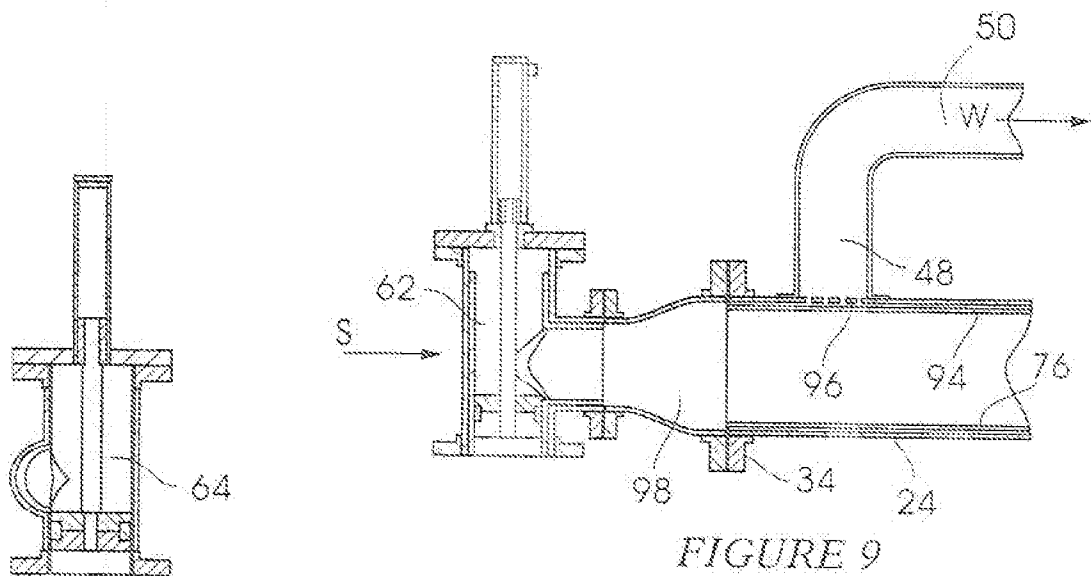
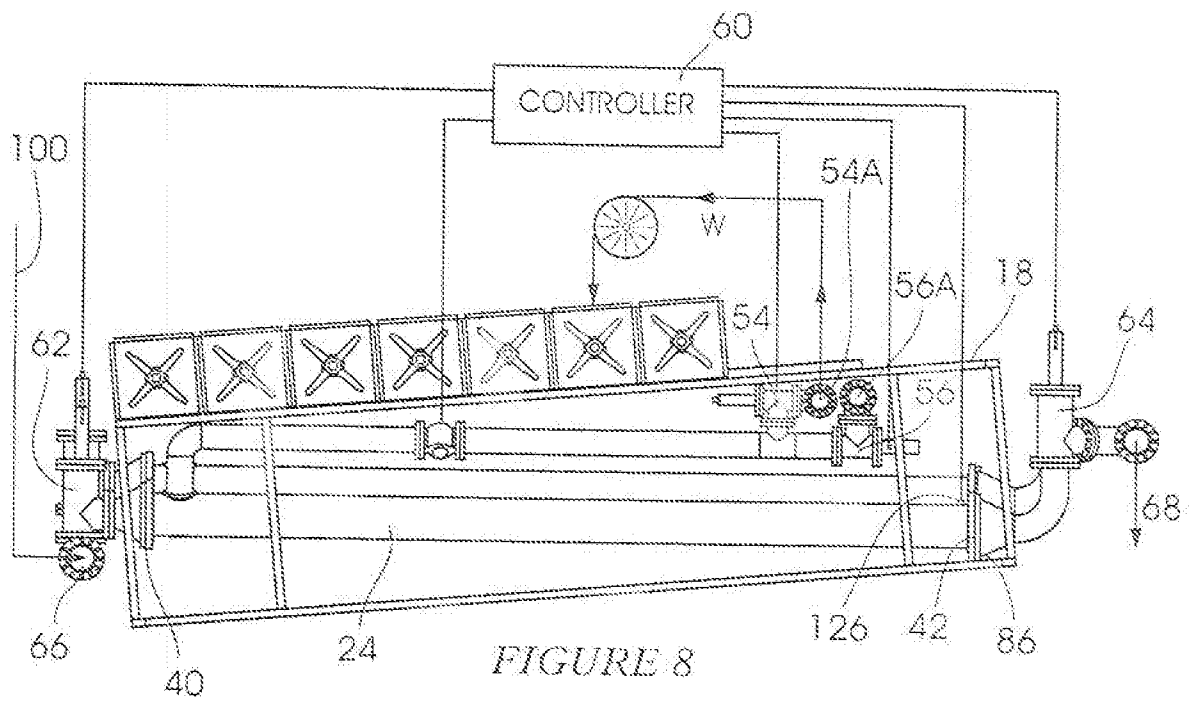


FIGURE 7



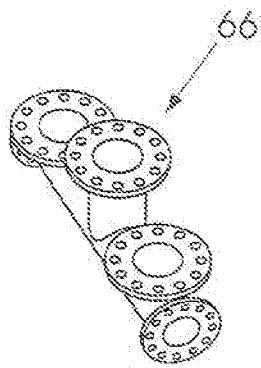


FIGURE 11A

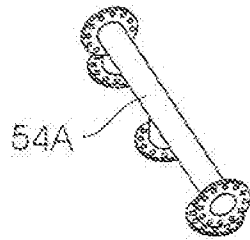


FIGURE 11B

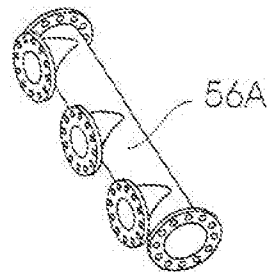


FIGURE 11C

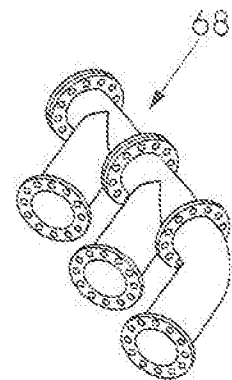


FIGURE 11D

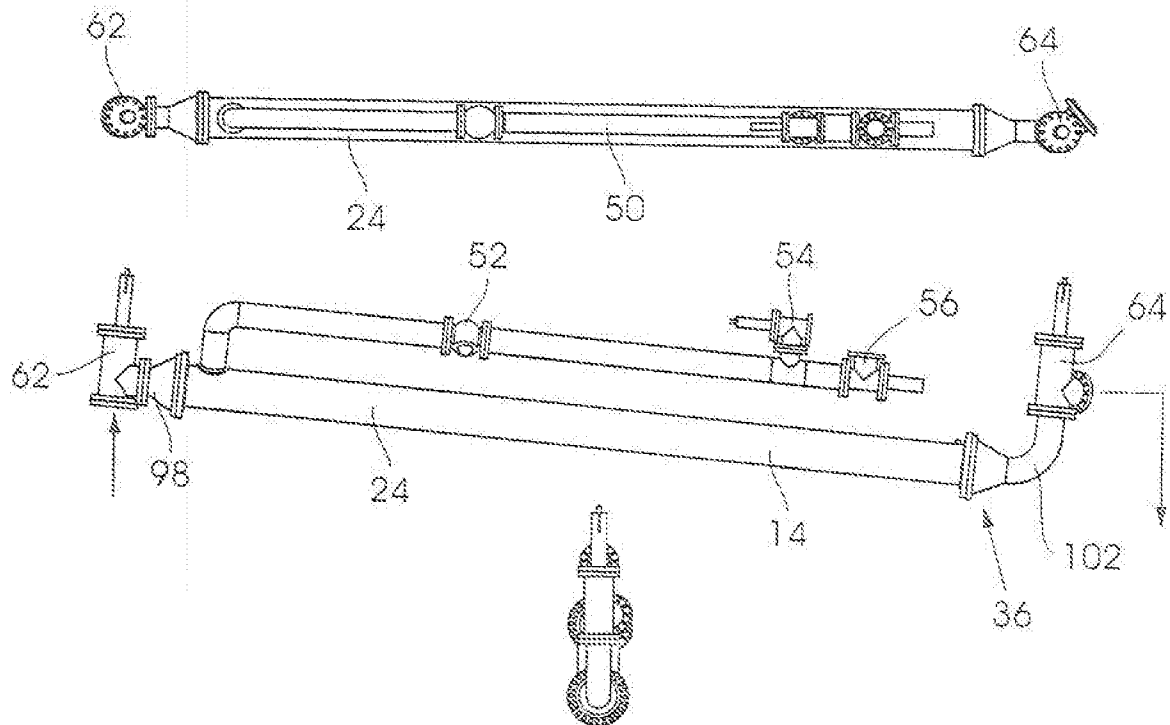


FIGURE 12