

(21) Application No: **0328580.6**  
(22) Date of Filing: **10.12.2003**  
(30) Priority Data:  
(31) **0229042** (32) **13.12.2002** (33) **GB**

(71) Applicant(s):  
**Marine Current Turbines Limited**  
**(Incorporated in the United Kingdom)**  
**The Manor House, Lutyens Close,**  
**Chineham, BASINGSTOKE, Hampshire,**  
**RG24 8AQ, United Kingdom**

(72) Inventor(s):  
**Peter Leonard Fraankel**

(74) Agent and/or Address for Service:  
**Russell-Rayner**  
**Business Centre West, Avenue One,**  
**Business Park,**  
**LETCHWORTH GARDEN CITY,**  
**Hertfordshire, SG6 2HB, United Kingdom**

(51) INT CL<sup>7</sup>:  
**F03B 13/00**

(52) UK CL (Edition W ):  
**F1T TEA T111 T121 T131 T149 T411**  
**F2W W19A W19B W19C W19D W19E W19X**

(56) Documents Cited:  
**GB 2348465 A** **GB 2348250 A**  
**GB 2347976 A** **GB 2311566 A**

(58) Field of Search:  
UK CL (Edition W ) **F1T, F2W**  
INT CL<sup>7</sup> **F03B**  
Other:

(54) Abstract Title: **Hydraulic transmission system for marine turbines**

(57) A hydraulic transmission system for use with at least one water current driven turbine rotor 20, where at least one high pressure pump 24 is driven by a turbine 20, delivering its high pressure output preferably via high pressure main 33, to a high speed hydraulic motor or turbine 35, which in turn drives an electric generator 38 or other machinery, preferably before the fluid re-circulates through low pressure supply line 34 back to the high pressure pump(s) 24. The hydraulic fluid may comprise water, and the water may be drawn from the operating environment. Top-up water may also be drawn via feed pump 45. The use of water may allow a higher level of leakage to be tolerated. The water inlet may also have a filter 42, and there may be a pressure balancing arrangement 32 in the high pressure main 33.

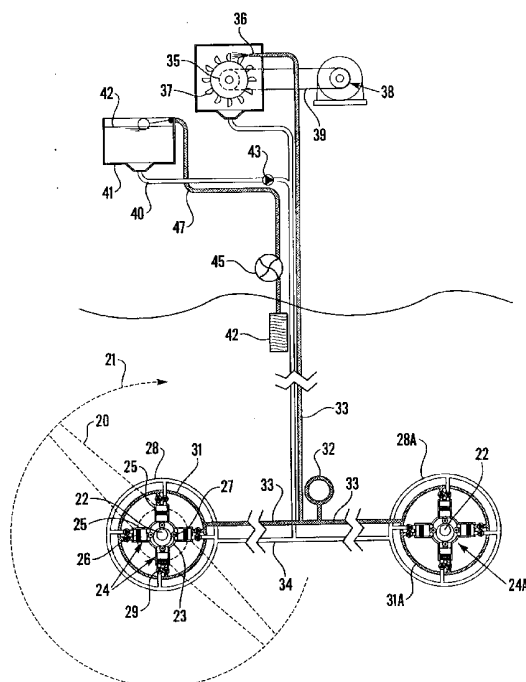
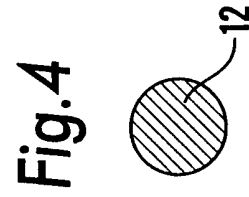
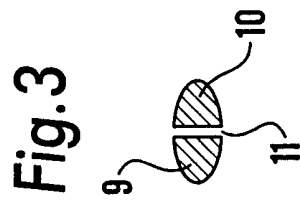
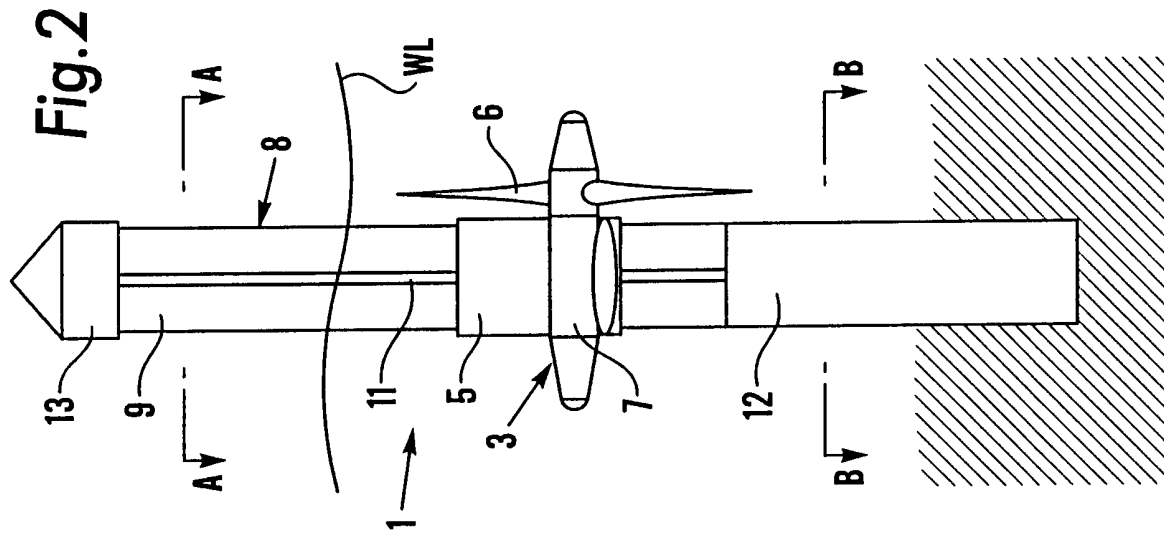
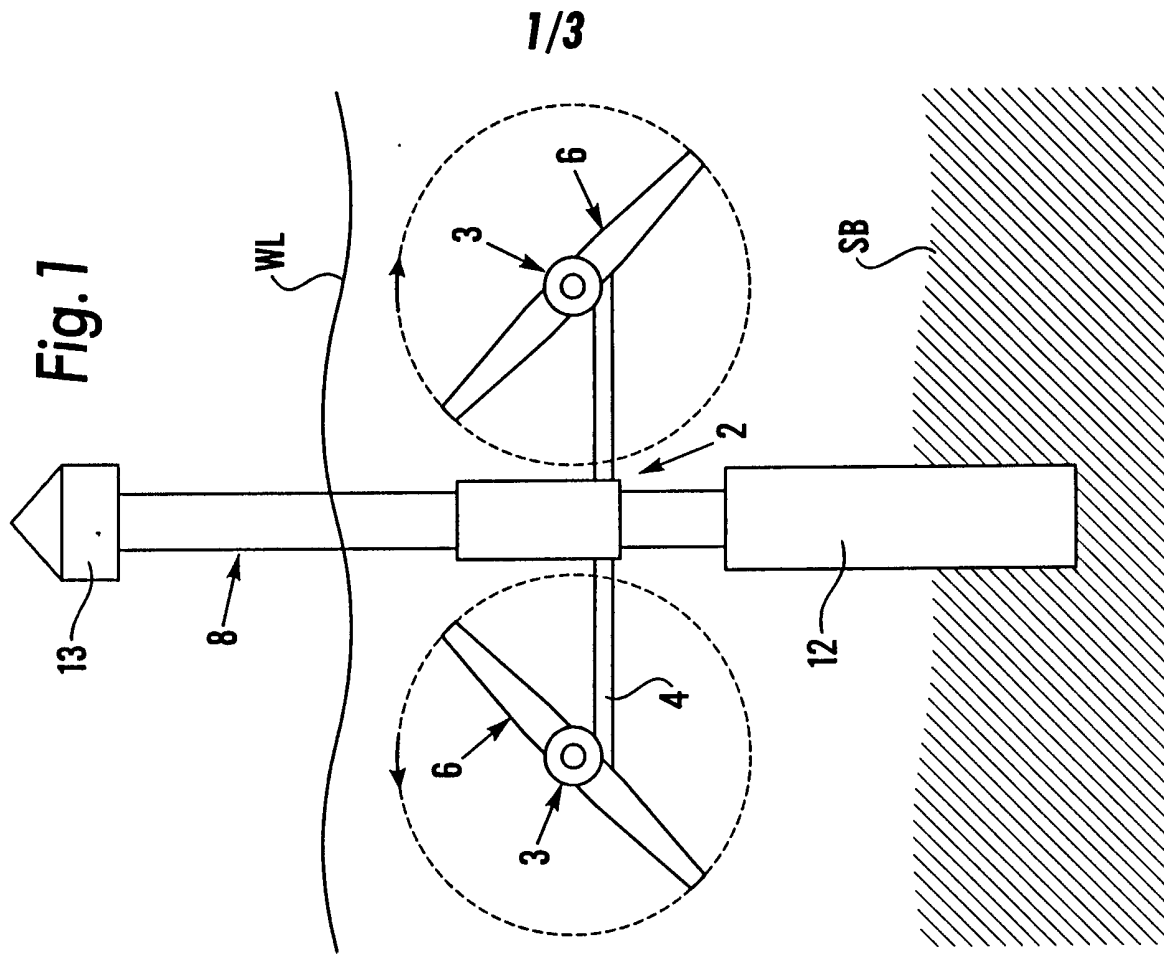
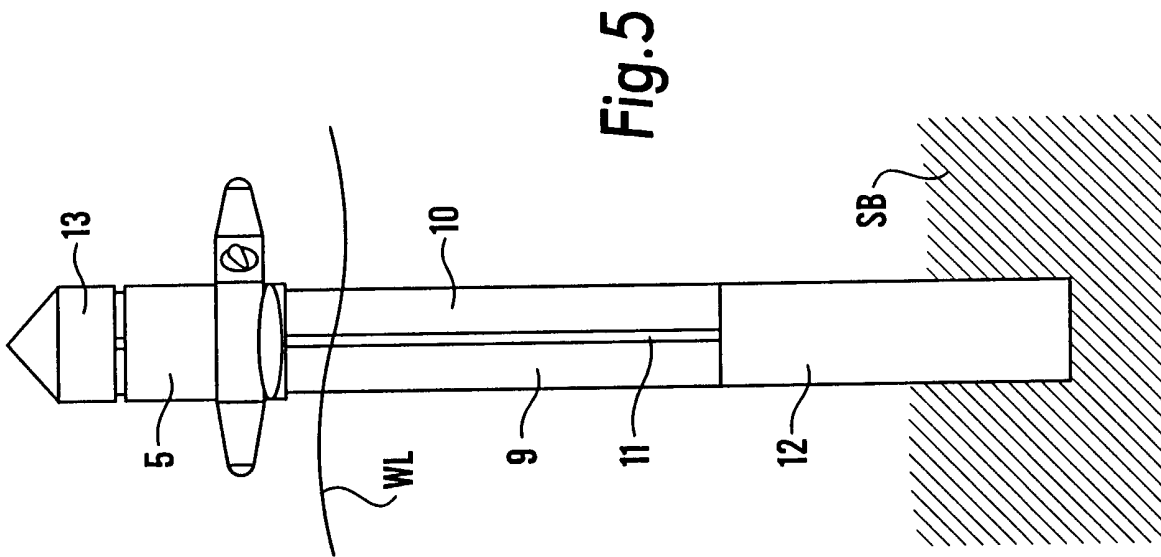
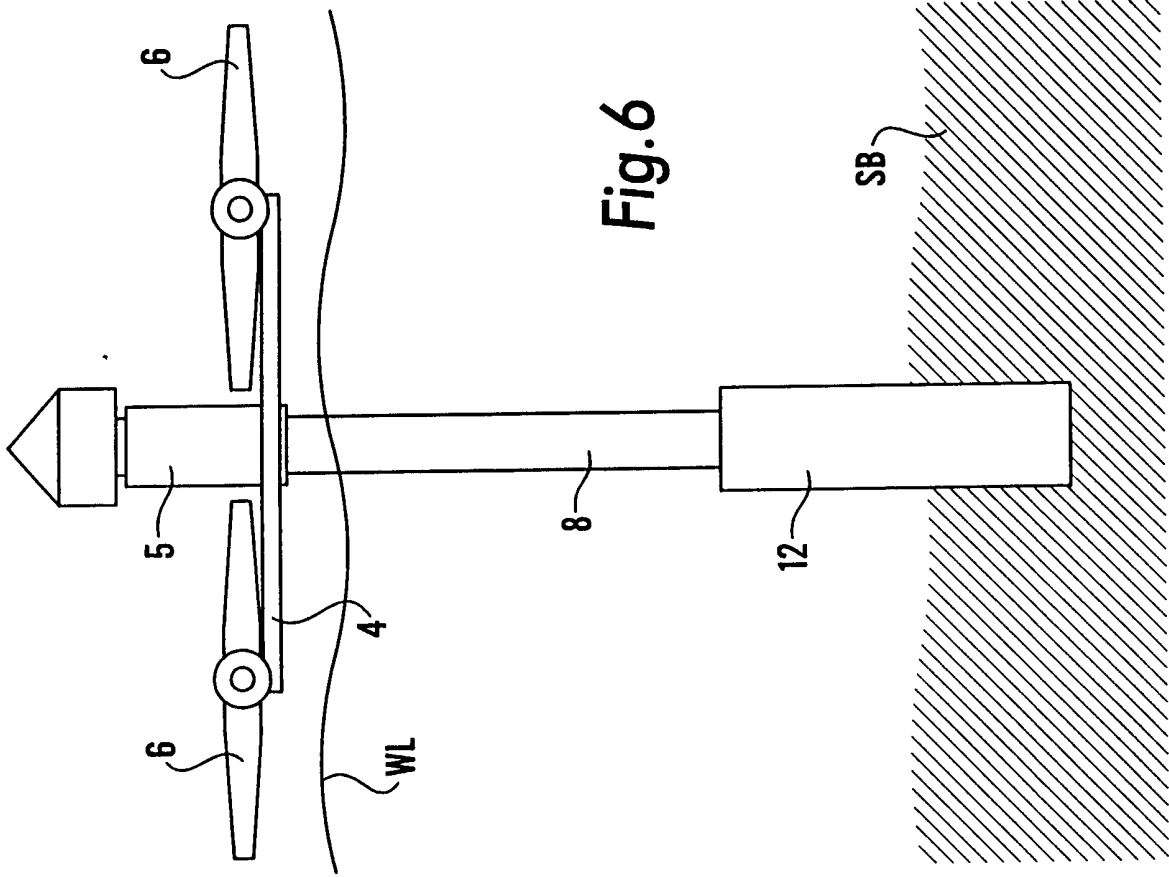


Fig.7





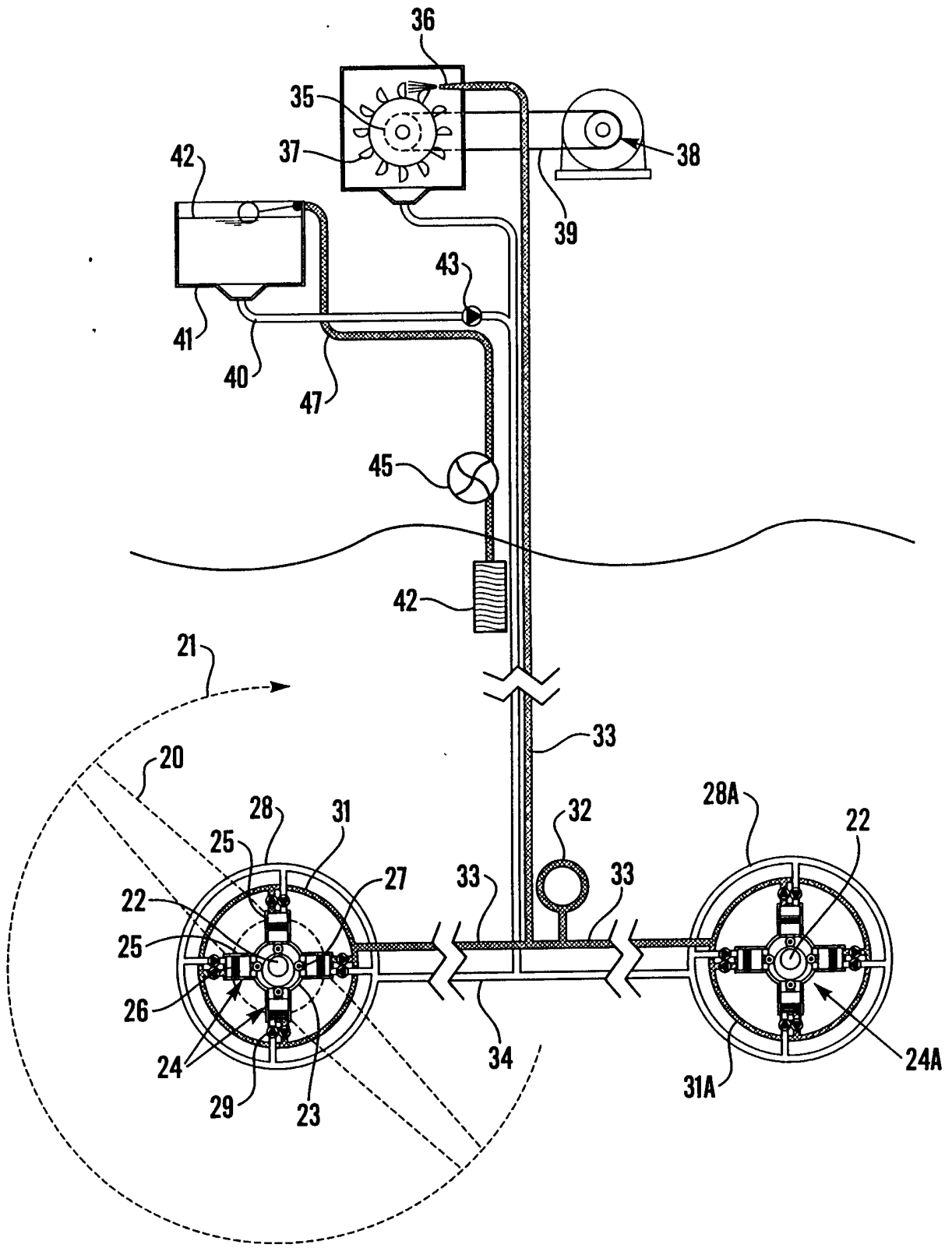


Fig.7

## HYDRAULIC SPEED-INCREASING TRANSMISSION FOR WATER CURRENT POWERED TURBINE

### BACKGROUND OF THE INVENTION

This invention relates to turbines and other such devices capable of interacting  
5 with a flow of fluid in such a manner as to transfer energy from the fluid to a  
mechanical device. This invention relates more particularly to turbines or other  
such devices arranged to be driven by the action of a flow of water or other liquid  
medium. Thus, the present invention relates in particular to the use of turbines and  
similar moving devices for extracting kinetic energy from flowing water for the  
10 purposes of utilising such kinetic energy to produce either electricity or shaft  
power for utilisation for a required purpose. Flowing water (which may be either  
fresh water or sea water) used in the context of this invention is a characteristic of  
tidal, marine, estuarial or river currents.

It is known how to use turbines for such purposes. For example, in our British  
15 Patents GB 2256011 B, GB 2311566 B and No 2348250 we have disclosed  
constructions pertaining to water driveable turbines; i.e. rotors supported within  
the water column of the sea, river or an estuary so that the flow of water may turn  
the rotor to produce shaft power and hence possibly electricity for utilisation for a  
required purpose.

20 In particular the present invention relates to a power transmission system for use  
with one or more such turbine rotors for extracting kinetic energy from flowing  
water and producing therefrom electricity by driving an electrical generator or  
alternator or for applying the power for some other useful purpose requiring a fast  
rotating shaft.

25 Generally a turbine for extracting kinetic energy from water currents, whether in a  
river or at sea, includes a rotor capable of interacting with the flow of water in  
such a way that some of the energy of motion of the passing mass of water causes

the rotor to rotate. No matter what kind of rotor is used, whether an axial flow or propeller type of rotor or a cross-flow rotor of the so-called Darrieus type, or even some other form of hydrofoil device reacting against the flow of water currents, the rotation of a rotor driven by the movement of water currents will be slow due  
5 to the fact that even the fastest of water currents only run at relatively slow speeds in the range from 2 to 4m/s at most and the rotor extremities cannot generally move much faster than 10 to 15m/s. Consequently only small devices can rotate at reasonably high speeds since the larger the device i.e., diameter of the rotor, generally the smaller the angular movement in a given time.

10 Therefore, it becomes necessary to provide some means for speeding up the output gained from the rotation of a slow moving rotor in order to effectively drive an electrical generator or other relatively high speed machinery. For example an axial flow tidal or river current turbine rotor 15m in diameter will typically rotate at about 10 revolutions per minute in a driving water current of 2  
15 to 2.5m/s (4 to 5 knots) but most conventional electricity generators typically require to be driven at shaft speeds of 1000, 1500 or more revolutions per minute. This situation indicates that there is therefore a need to increase the speed of the main turbine shaft by a factor of 100 or more. The most generally proposed technique, which is prior art, is by using a multistage gearbox. However gearboxes  
20 of such a kind are complicated mechanically, heavy to handle, costly, suffer significant wear and require regular maintenance to replace the lubricant conventionally provided between relatively moving components of the turbines. Furthermore, gearboxes conventionally involved also introduce a hazard to the local environment should the lubricating oil leak out for any reason.

## 25 THE PRIOR ART

It is known how to use turbines for such above mentioned purposes. For example, in our British Patents GB 2256011 B, GB 2311566 B and No 2348250 we have disclosed constructions pertaining to water driveable turbines; i.e. rotors

supported within the water column of the sea, river or an estuary so that the flow of water may turn the rotor to produce shaft power and hence possibly electricity for utilisation for a required purpose.

Thus the concept of immersing a rotor in a water current in order to extract energy  
5 has been tested and described, as for example, in our above mentioned British Patents

#### OBJECT OF THE INVENTION

The object of the invention is to provide a method of and means for increasing the effective rotational speed of a rotating member.

#### 10 STATEMENTS OF THE INVENTION

According to a first aspect of the invention there is provided a hydraulic transmission system for use with at least one water current driven turbine rotor, characterised in that a low speed high pressure pump or pumps is/are arranged to receive operational drive from the turbine rotor, and to deliver high pressure  
15 output to a high speed hydraulic motor or turbine in such manner as to produce an increase of the shaft or motor speed accompanied by a corresponding reduction of torque required to drive electrical generators or other machinery as compared with the shaft speed of the turbine rotor or rotors.

Preferably, a substantially closed hydraulic fluid circuit is provided for said  
20 hydraulic fluid associated with the low speed high pressure pump or pumps

Conveniently the hydraulic fluid for said high pressure pump or pumps is/are arranged to be recirculated from a high speed hydraulic motor or turbine through a low pressure fluid return line or lines to feed said low-speed high-pressure hydraulic pump or pumps.

Preferably the hydraulic fluid is water.

Conveniently, any loss of the water from the system is arranged to be made up by drawing replacement water from the water within which said rotor or rotors is/are is operationally located

- 5 In a preferred arrangement such make up water is filtered to remove suspended solids or other undesirable pollutants before being stored in a header tank situated in such a position that it can feed make-up water into the system to replace and water lost through leakage

10 Since the hydraulic fluid is water is drawn from the operating environment of the turbine or turbines, a relatively high degree of fluid leakage can be tolerated, thereby to allow the use of larger than would otherwise be acceptable clearances relative movement for seals, the arrangement being such that the operation of the pumps can be optimised for mechanical efficiency rather than 100% retention of hydraulic fluid.

- 15 Preferably each said rotor is associated with a plurality of separate pumps arranged to be operationally driven from the associated rotor, and in that the hydraulic fluid inputs to the pumps are connected to receive fluid from a low pressure fluid plenum and the output sides of all said pumps are associated with a common high pressure plenum connecting via high pressure fluid circuit with the  
20 hydraulic motor or rotor coupled to drive a generator or other machinery

In accordance with a further aspect of the invention a water drivable turbine is provided with a hydraulic power transmission system for increasing the effective speed of the turbine.



In accordance with a further aspect of the invention a hydraulic power transmission system using water as a working fluid is utilised to achieve the desired increment in speed to couple a low speed tidal or river current turbine rotor to a conventional electrical generator or to other high speed machinery

- 5 In a preferred arrangement it is proposed to directly couple a low speed, positive displacement hydraulic pump to the turbine rotor drive shaft

In particular the hydraulic pump may be of various types, such as, for example, a cam or crank driven single or multi-cylinder piston or plunger type of pump, or an internal or external type gear pump, a lobe pump or a vane pump

- 10 Conveniently, pumps utilised may be presented in a variety of configurations, such that, for example, a piston or plunger pump may have a multiplicity of cylinders disposed radially around the cam or driving crank on the main shaft, or the cylinders may be disposed axially along a camshaft or crankshaft, or there may be a series of radially disposed cylinders set axially along a camshaft or  
15 crankshaft

- The concepts of the invention may be applied to water current turbines with more than one rotor, in which case each rotor will be coupled to a similar low speed, positive displacement pump fed with the same working fluid that the turbine runs in, whereby if the pump is in the sea it will be sea water, if in an inland river it  
20 may be freshwater. Therefore any minor leakage of hydraulic fluid will not create any environmental problem of polluting the surroundings and is acceptable.

- In a particular arrangement individual cylinders (with piston or plunger pumps) or the pump output will draw in water via non-return valves from a low pressure or supply manifold and similarly they will deliver at a higher pressure pumped  
25 water through a non-return valve into a high pressure manifold.

In practice the low pressure manifold will be connected to a low pressure supply pipe or feed pipe which will carry an adequate supply of working fluid to meet the needs of the pump(s). Similarly, the high pressure manifold will in turn be connected to a high pressure supply or transmission pipe and it may also interface  
5 with an accumulator capable of absorbing fluctuations or pulses in the output caused by the use of piston or plunger pumps (the use of an accumulator may not be necessary when rotary positive displacement pumps such as gear pumps are used, as their output tends to be relatively smooth and free from pressure pulses)

The low pressure and the high pressure transmission pipes will be led through the  
10 support structure of the tidal turbine to a convenient location for placing a water motor or Pelton Turbine connected to a generator. The water motor or Pelton turbine will generally be driven by one or more jets of water impinging on a specially shaped runner, such devices are prior art and well known

In the application of this invention to the tidal turbine concept we have previously  
15 described in our British Patents GB 2311566 and 2348250, the turbines are mounted on a mono-piled support structure that is installed in a socket drilled into the seabed or river bed and the upper end of said support mono-pile emerges above the surface of the flowing water current. When the concept of the invention is applied to this method for extracting kinetic energy from currents then the low  
20 pressure and the high pressure transmission pipes will carry the flow to and from a water motor or Pelton Turbine driving a generator that is preferably located above the surface of the water in a weather proof housing on the top of the supporting mono-pile.

Conveniently, however the housing for the water motor or Pelton Turbine may in  
25 some cases be a water tight casing located under the surface in the case of turbine/control systems that do not penetrate the water surface

Preferably, the water used in the system of the present invention is filtered so as to be free of significant quantities of suspended solids or debris which would otherwise prematurely wear the components of both the pumps and the water motor or Pelton Turbine.

- 5      Conveniently, also the water may also be dosed with a non-harmful (bio-degradable or bio-friendly) lubricant to help minimise wear and tear of seals and moving components in the system

10      Preferably any makeup water required for the proposals of the present invention is drawn through a strainer and then a filter by an ancillary pump and fed into a header tank or storage tank, it being arranged that said pump only functions at times when a float or other level indicating transducer signals that the water level in the header or storage tank has fallen below some predetermined level and ceases to function when the header or storage tank is replenished to another higher predetermined level

- 15      In particular the aforementioned storage or header tank is linked to the water return feed pipe which collects water from below the Pelton Turbine or water motor and returns it to the feed manifold of the low speed, high-pressure pump (or pumps).

#### BRIEF DESCRIPTION OF THE DRAWINGS

- 20      For a better understanding of the invention and to show how to carry the same into effect reference will now be made to the accompanying drawings in which.-

Figure 1 is a schematic front view of a water current turbine system as disclosed in our co-pending British Patent Application No 0327429,7 the Figures illustrating the installation when the turbines and associated rotors are submerged in water;

Figure 2 is a schematic side view of the installation of Figure 1,

Figure 3 is a section on the line A-A of Figure 1,

Figure 4 is a section on the line B-B of Figure 1;

Figures 5 and 6 schematically illustrate the installation of Figures 1 to 4, when the  
5 turbines and associated rotors are raised to a location above seal level, and

Figure 7 is a schematic diagram schematically illustrating an embodiment of the  
present invention when used with an installation illustrated in Figures 1 to 6

Referring now to Figures 1 to 4 these Figures illustrate a support column 1 for  
mounting a turbine assembly 2. The lower end of the column 1 is embedded in a  
10 river/seabed SB and is of such length that the upper end thereof is above water  
level WL. In the Figures 1 to 4 the turbine assembly is shown as comprising two  
turbine units 3 mounted one to each of the extremities of a horizontal wing-like  
support structure 4 including an internal spar (not separately shown) within an  
outer housing (not separately shown) streamlined in cross section. The structure 4  
15 is carried by a collar like sleeve 5 longitudinally displaceable lengthways of the  
support column 1. The profiling of the structure 4 is such as to assist in reducing  
as far as possible the creation of undesirable water drag effects in water passing  
over the surface of the structure 4 and to minimise the water wake at the trailing  
edge of the structure. In practice the direction of water flow across the structure  
20 can be tidal and thus reversible in direction across the structure 4. This requires  
that the profiling of the structure has also to be bi-directional so that it is  
operationally efficient in both directions of water flows

Each turbine unit 3 includes a rotor 6 carried by a rotor shaft (not separately  
shown) that forms part of a very schematically indicated rotor rotation  
25 transmission system 7 including a drive-train (not shown). The drive-train is

essentially a mechanism for applying the rotor shaft power for some useful purpose i.e., to generate electricity and may consist of a gearbox and generator, a direct drive generator or an hydraulic pump driving a generator via a hydraulic motor.

- 5 The sleeve 5 fits sufficiently closely to the upper section 8 of the column 1 as to be selectively displaceable length ways of the column as will be considered hereinafter The upper section 8 of the column is also streamlined by being of an overall oval/elliptical profile so as to minimise the water flow wake and to maximise the resistance to bending in the directions of water flow normal to the  
10 rotor plane.

In the embodiment of the system illustrated, the upper section 8 of the column comprises as shown in Figure 3 two face to face twin "D" profiled part columns 9 and 10 with a gap 11 between them through which the main spar of the support structure 4 can fit.

- 15 The sleeve 5, the structure 4, and the turbine units 3 are assembled together as a composite unit to form the assembly 2. This assembly is displaceable bodily lengthways of the upper section of the column by sliding the sleeve 5 up or down the upper section 8 of the column 1. The section 8 is of such length that the extent of possible displacement enables the assembly 2 to be positioned below water  
20 level WL as is shown in Figures 1 and 2 and positioned above water level as is shown in Figures 5 and 6 so that the assembly 2 can be conveniently positioned with the rotors 6 in a stopped setting for the purposes of maintenance or other activities to be carried out upon the assembly.

- In Figures 1 and 2 the assembly 2 is shown as being located with the axes of the  
25 turbine unit rotors 6 positioned approximately halfway between the water surface WL and the seabed SB

It will be noted from the Figure 4 section on the line B-B of Figure 2 that the lower or base section 13 of the column is of a solid circular cross-section. A housing 13 is provided at the upper end of the columns 9 and 10.

5 Whilst the above disclosed embodiment is considered advantageous and preferred by the Applicants but is not an essential element for applying this invention to a turbine installation

Referring now to Figure 7, this Figure is a schematic diagram showing an embodiment of a system incorporating the concepts of the present invention and in particular illustrates how the system shown therein could be applied to an  
10 installation such as that in shown in Figures 1 to 6

Although Figure 7 shows the concepts of invention as applied to a turbine installation involving two rotors the concepts of the present invention could be applied to a single turbine installation or to installations involving more than two turbine

15 Referring now to Figure 7 in which a rotor 20 of a turbine installation (not shown in detail) is depicted in broken lines, the direction of rotor rotation being indicated by the part circular broken line 21

The rotor 20 is arranged to rotate a shaft 22 mounting a cam drive 23 comprising in this example of an offset circular profile. The cam drive 23 is arranged to  
20 operate a pump assembly 24. As shown the assembly 24 incorporates four cylinders 25. The cylinders 25 are, in this example, symmetrically disposed around the cam drive 23 with their centre lines or longitudinal axes in the plane of the cam drive and radially directed with respect to the shaft 22.

The pistons or plungers 26 associated with the cylinders 25 are reciprocated  
25 within their associated cylinders 25 by roller type cam followers 27 forming part

of the cam drive. In practice, return spring arrangements (not shown) can be provided inside each cylinder. The pump concept illustrated in Figure 7 can be regarded as being used purely by way of example. In practice, the pump unit/units used can be of any form suitable for the intended purpose. Other piston  
5 or plunger type pump unit configurations may be used. For example, gear, vane, lobe or other types of low speed, high pressure positive-displacement pumps could be used..

Inlet liquid i.e., inlet water for the pump assembly 24 is introduced into the cylinders 25 by way of a circular plenum or ring main 28. This water is  
10 introduced into each cylinder 25 by way of an associated non-return water inlet valve 29. That is each cylinder has a non-return water inlet valve 29.

It should be noted that the shape of this plenum or ring main 28 may vary to suit the form of the pump unit/pump installation being used and may not necessarily take the shape of a ring main 27 and four feed cylinders 25. For example, in some  
15 installations involving a single entry point to a single pump a single feed pipe may well suffice.

The higher pressure water produced by the pumping action of the pump unit/units is expelled at this higher pressure from the pump cylinders 25 via non-return valves into a higher pressure water plenum or ring main 31. This plenum/ring  
20 main 30 interconnects to an optional surge-chamber or accumulator 32 capable of absorbing pulses in the liquid flow to produce a pressure wise smoothed output is fed by way of a higher pressure main 33.

Similarly feed water to the pumps arrives at the feed plenum 27 via a low pressure supply line 34.

25 In a multi-turbine installation as represented by Figure 7 the pump or pump assembly 24A associated with the other turbine rotors (one such pump unit being indicated at 24A, will incorporate plenums or ring mains 27A, 31A that are

hydraulically coupled to the above discussed outlet and inlet feed lines 33 and 34. In other words the inlet and outlet feed lines 34,33 can be common to all of the turbines of an installation.

5 The high pressure water main 33 transports the high pressure water emitted from the pumps 24 to a water motor or Pelton Turbine 35 that provides an efficient and well known mechanism for obtaining a high speed output from a jet (or in some cases several jets) of water. In this case the high pressure water main 33 terminates in one (or more) nozzles 36 which cause a high velocity jet (or jets) of water to impinge on the buckets or blades 37 of the water motor or Pelton Turbine  
10 35. In many cases a multi-jet Pelton Turbine 35 may be used although the Figure for simplicity only shows the single jet option. The advantage of a multi-jet installation is that better part-load efficiency may be gained by using fewer jets when only a limited water supply is available.

The Figure 7 also shows the water motor or Pelton Turbine 35 driving an  
15 electrical generator 38 by way of pulleys and a belt transmission 39. This is primarily to clarify the principles being illustrated since in practice the generator 38 may in fact be direct coupled to the water motor or Pelton Turbine 35 (i.e. the shaft of the generator directly engaged with the shaft of the water motor), but equally some speed changing transmission such as a belt or belts may be used.

20 Since some of the water used as hydraulic fluid may leak from the circuit, especially from the high pressure pump or pumps (assemblies 24), any losses will need to be made up to ensure a continuous feed supply to the pump or pumps. In practice, it may well be desirable to allow some leakage since good clearances and less than perfect sealing will in all probability reduce the mechanical losses in  
25 the pump(s) and thereby improve the overall system efficiency;. This arrangement in practice could also very probably make it easier to obtain long intervals before any pump seals need replacement.



To accommodate any such leakage a make-up water supply 40 is provided in which a header tank 41 is mounted such that its water static level 42 is immediately below the water motor or Pelton Turbine 35 as illustrated, so that if the level in the return supply pipe 34 falls significantly below that in the header tank, some make up water will flow from the header tank through a non-return valve 43 into the circuit near the top of the low pressure return supply pipe 33.

The header tank 41 is topped up when a level sensor 44 detects that the water level has fallen below some predetermined level; when this happens a small feed pump 45 is operated to draw water from the surroundings to the system through an intake with a strainer and filter system 46 and to pump it through a makeup water feed pipe 47 into the header tank 41. When the water level in the header tank 41 exceeds a predetermined height, then the feed pump 45 is switched off. In most cases said feed pump will be electrically energised

## CLAIMS

1 A hydraulic transmission system for use with at least one water current driven turbine rotor, characterised in that a low speed high pressure pump or pumps is/are arranged to receive operational drive from the turbine rotor, and to deliver  
5 high pressure output to a high speed hydraulic motor or turbine in such manner as to produce an increase of the shaft or motor speed accompanied by a corresponding reduction of torque required to drive electrical generators or other machinery as compared with the shaft speed of the turbine rotor or rotors

2. A hydraulic transmission system as in claim 1, and characterised in that a  
10 substantially closed hydraulic fluid circuit is provided for said hydraulic fluid associated with the low speed high pressure pump or pumps

3 A hydraulic transmission system as claimed in claim 1 or 2, and characterised in that the hydraulic fluid for said high pressure pump or pumps is/are arranged to be recirculated from a high speed hydraulic motor or turbine through a low  
15 pressure fluid return line or lines to feed said low-speed high-pressure hydraulic pump or pumps.

4. A hydraulic transmission system as in claim 1 2 or 3, and characterised in that the hydraulic fluid is water.

5. A hydraulic transmission system as claimed in claim 4, characterised in that  
20 the water required is originally be drawn from the water within which said turbine rotor or rotors is/are is operationally located..

6. A hydraulic transmission system as claimed in claim 5, and characterised in that any loss of the water is arranged to be made up by drawing replacement water from the water within which said rotor or rotors is/are is operationally located.

7. A hydraulic transmission system as claimed in claim 6, and characterised in that such make up water is filtered to remove suspended solids or other undesirable pollutants before being stored in a header tank situated in such a position that it can feed make-up water into the system to replace and water lost  
5 through leakage.

8. A hydraulic transmission system as in claim 4, 5,6 or 7, and characterised in that since the hydraulic fluid is water is drawn from the operating environment of the turbine or turbines, a relatively high degree of fluid leakage can be tolerated, thereby to allow the use of larger than would otherwise be acceptable clearances  
10 relative movement for seals, the arrangement being such that the operation of the pumps can be optimised for mechanical efficiency rather than 100% retention of hydraulic fluid.

9. A hydraulic transmission system as claimed in any one of the preceding claims, and characterised in that each said rotor is associated with a plurality of separate  
15 pumps arranged to be operationally driven from the associated rotor, and in that the hydraulic fluid inputs to the pumps are connected to receive fluid from a low pressure fluid plenum and the output sides of all said pumps are associated with a common high pressure plenum connecting via high pressure fluid circuit with the hydraulic motor or rotor coupled to drive a generator or other machinery

20 10. A hydraulic transmission system as claimed in claim 9, and characterised in that a surge or pressure balancing arrangement is provided in the high pressure fluid circuit.

11. A hydraulic transmission system constructed and arranged to operate substantially as herein before described with reference to Figure 7 of the  
25 accompanying drawings.

12 A marine turbine installation incorporating a hydraulic transmission system as claimed in any one of the preceding claims.

13 A water drivable turbine installation including a hydraulic power transmission system for increasing the effective rotational speed of the turbine.

- 5      14 A marine turbine installation incorporating a hydraulic transmission system substantially as herein before described with reference to the accompanying drawings.



INVESTOR IN PEOPLE

Application No: GB0328580.6

17

Examiner: Mr Andy Harding

Claims searched: 1 - 13

Date of search: 28 April 2004

**Patents Act 1977: Search Report under Section 17****Documents considered to be relevant:**

Category	Relevant to claims	Identity of document and passage or figure of particular reference
X	1 - 8, 12 & 13	GB 2347976 A (I T POWER LTD) See entire document, especially page 7, lines 1 & 2, and page 8, lines 3 - 12.
X	1 - 8, 12 & 13	GB 2348250 A (I T POWER LTD) See entire document, especially page 7, lines 20 & 21, and page 8, line 21 - page 9, line 2.
X	1 - 8, 12 & 13	GB 2348465 A (I T POWER LTD) See entire document, especially page 5, lines 11 & 12, and page 6, lines 11 - 20
X	1 - 3, 12 & 13	GB 2311566 A (I T POWER LTD) See entire document, especially page 6, lines 2 - 5

**Categories:**

X Document indicating lack of novelty or inventive step	A Document indicating technological background and/or state of the art
Y Document indicating lack of inventive step if combined with one or more other documents of same category	P Document published on or after the declared priority date but before the filing date of this invention.
& Member of the same patent family	E Patent document published on or after, but with priority date earlier than, the filing date of this application

**Field of Search:**Search of GB, EP, WO & US patent documents classified in the following areas of the UKC<sup>W</sup> :

F1T; F2W

Worldwide search of patent documents classified in the following areas of the IPC<sup>07</sup>

F03B

The following online and other databases have been used in the preparation of this search report

EPODOC, WPI, PAJ, OPTICS