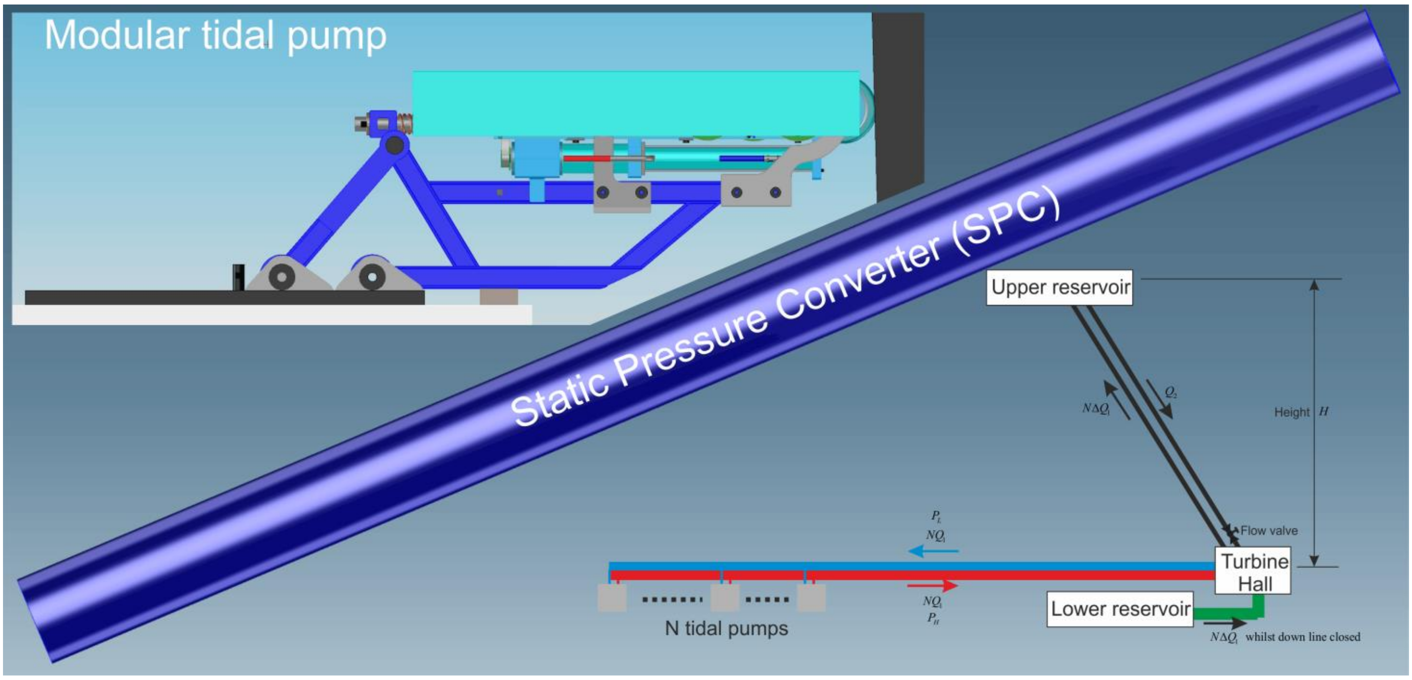
Organisation: SPC-Tidal

SPC Tidal Height Change Energy Proposal: Concept

Document: 170322_2



Abstract

Land-based power extraction from tidal height change using closed circuit SPC technology. Energy storage is used to enable electricity production at peak demand. Tidal power availability enhanced via vessel use. Modular concept and no direct contact with seawater. The concept may lay the basis for the extraction of wave energy.

March 2017

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Preface

Sea energy availability is not questioned, but its economic extraction is not evident. One may list the more evident components of sea energy, in their order of ease of extraction, as follows:

a) Tidal height change
b) Tidal currents
c) Wave motion

Beyond these are the less evident, but probably of greater importance in the distant future, namely

d) Accelerative and higher order deformation rates
e) Depth

The extraction of energy from a) to e) requires a more advanced fluid dynamic approach than is currently covered by classical theory. The following presentation limits itself to component a) energy extraction.

The tidal flow around the UK coast is both reliable and amenable to long term forecasting. The tide manifests itself as a sea level water height change over a period of roughly six hours in one direction. The complete cycle from high water back to high water is completed in approximately twelve hours. During any month, the tide is said to be in a state of neaps, smaller height changes, or springs, larger height changes. Each of these states lasts approximately two weeks and represents a smooth sinusoidal like transfer from one to the other. As an example, the height difference corresponding to minimum neaps or maximum springs at Torbay lies in the region of 3m and greater than 5m, respectively. In the Bristol Channel the height rises are more than double this.

It is evident that the unloading and loading of vessels, especially large ones, can be included in the tidal concept. Many metres of height change occur during these manoeuvres on “large” vessels. Further, the locking of vessels will provide a rapid “tidal” effect. This document contains a proposal for utilising these “tidal” effects as an energy source and, in particular, the generation of electricity during peak load requirement.

Desired characteristics

1. Tidal Machine: Independent of tide direction and total tide range

In order to accommodate the diverse range of tides and vessel movement, it is preferable that the so-called tidal power generator unit is flexible in the sense that only the instantaneous movement, independent of direction up or down, needs to be considered. In other words, neither the maximum tidal variation nor direction should be relevant to the operating principle of the machine.

2. Tidal Machine: Capable of energy extraction at variable rates

As the tidal variation is a non-steady time dependent function, direct conversion to electrical power is likely to be very inefficient and/or very costly. This implies that the tidal machine must be capable of extracting variable low “density” energy in a simple manner so that it can be upgraded at a later date.

3. Corrosion: No components directly in contact with seawater

Due to the extremely corrosive nature of seawater and its charge (sand etc.), it is essential for economic long-life functioning that the tidal machine does not involve any seawater submerged components. It is possible that exotic materials could allow a reasonable machine life cycle, but the exotics’ costs are currently far too capital intensive.

4. Energy storage

Storage will allow for the progressive accumulation of low grade energy that can be upgraded at a later date.

The logistics of vessel movement will not necessarily be compatible with the timing of the additional electrical energy requirement. In addition, the irregular energy availability does not lend itself to simple transformation to electric power. Consequently, energy storage is an essential component for any successful exploitation of the tidal energy concept.

5. Tidal Machine: Low capital cost

From a financial viability point of view, the energy "density" availability from tidal height change must be considered as low when compared to that of oil. Further, the overall energy contribution to the total UK energy requirement for the future will be small but will grow with increased trade and productivity. Tidal power is best thought of as a peak load contributor, so reducing the maximum installed capacity requirement.

6. Tidal Machine: Amenable to rapid development

The significance of rapid development lies in the ability either to simplify and/or to mass produce. Another advantage would be the upgrade of the machine efficiency. To comply with this desired characteristic, the Tidal Machine must start life as a very simple mechanical concept.

The Tidal Machine proposed below meets all the characteristics 1 to 6 and so lends itself to mass production techniques rather than requiring costly bespoke manufacture. Further, the concept may also form the basis for the extraction of the component energies listed in Preface items b), c) and d). Component source e) is currently under investigation by the author in a separate development.

Introduction

Three groupings comprise the Tidal Power Generation Unit (TPGU) proposal, namely pier-based tidal pumps, remote electric power generating station (Turbine hall) and remote energy storage (Upper and lower reservoirs). All groupings are linked by "closed circuit" hydraulic supply lines.

Several versions have been evaluated theoretically. The first technically feasible TPGU, named TPGU-8, was described on the website http://www.spc-tidal.co.uk/ . The TPGU-8 article has now been removed and replaced by the current document. Only the tidal pump component of the TPGU has yet to be proven. The main thrust of the current development is the design of a low capital cost tidal pump. The current situation is summarised in Table.1.

Tidal project	Global hydraulic efficiency %	Global electrical efficiency %	Annual Electrical energy MWh	Capital cost/tidal pump £	Capital cost £/kWh
TPGU-8 June 2016	4	2	4.380	120,000	27.40
TPGU-10 March 2017	4	2	5.475	10,000	1.83
TPGU-X (Target aim)	14	10	27.375	10,000	0.37
TPGU-X mass produced	14	10	27.375	4,000	0.15

Table 1: TPGU performance and tidal pump capital cost. Conditions: 1000 ton vessel and tide rate of 1cm/min.

For height rate changes greater than 1cm/min (total height change 3.6m) the energy production increases in a linear fashion and the capital cost decreases in a non-linear manner due to the requirement of fewer amplification stages and/or smaller eccentric pumps. Fewer amplification stages results in an immediate increase in tidal pump efficiency. The size of the eccentric pump is a decreasing function of available rotation speed which is dictated by the tidal rate.

Tidal Power Generating Unit concept

The basic TPGU concept, shown in Fig.1, refers to a closed circuit system driven by N tidal pumps.

The term closed circuit refers to the fact that only sweet water is circulated through the various units comprising the system without "liquid loss". The device employed to achieve this is a Static Pressure Converter (SPC). The SPC is a spin-off from an unpublished fluid dynamic theory[i][1], and the practical realisation of SPC systems will be referred to as SPC technology. A document describing the SPC is available on the website http://www.spc-tidal.co.uk/ .

The modular aspect of the tidal pumps derives from the fact that they can be mass produced units designed to cope with vessels of 100 or 1000 tons displacement. Larger units are not excluded, but initially the flexibility of the smaller units may prove to be beneficial. The SPC also lends itself to modularisation so that mass production techniques can be applied.

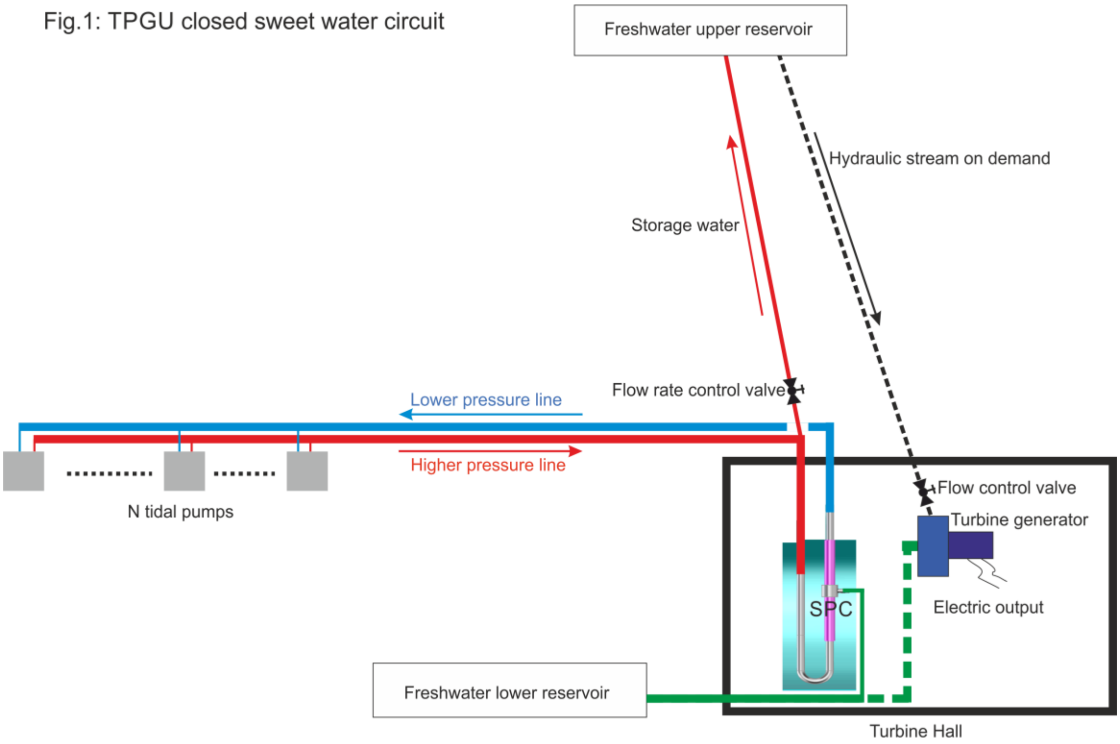

Fig.1: Basic Tidal Power Generation Unit TPGU concept

1. Pier-based tidal pump TPGU-10

A CAD image of the Pier-based tidal pump is shown in Fig.2. The principal components are itemised on the image.

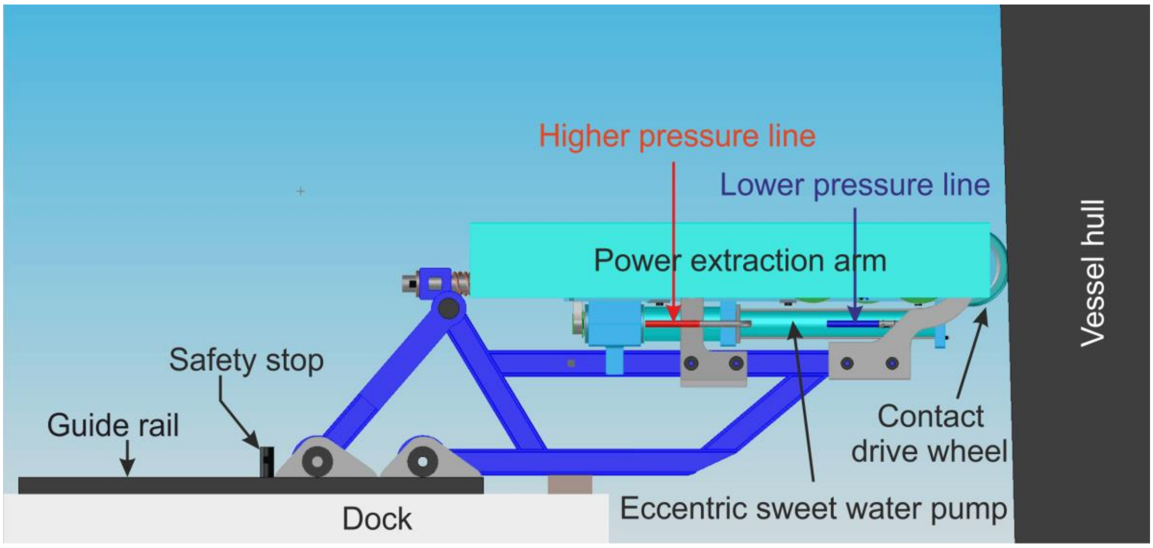

Fig.2: Pier-based tidal pump. Image shows power extraction arm in operating position.

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[1] See note under Footnotes

In order to manoeuvre the vessel without risk of collision with the tidal pump, the draw bridge type power extraction arm is raised over the dock as shown in Fig.3. The arm lift mechanism is actuated by drawing the rear foot backwards using a vehicle and a tow rope.

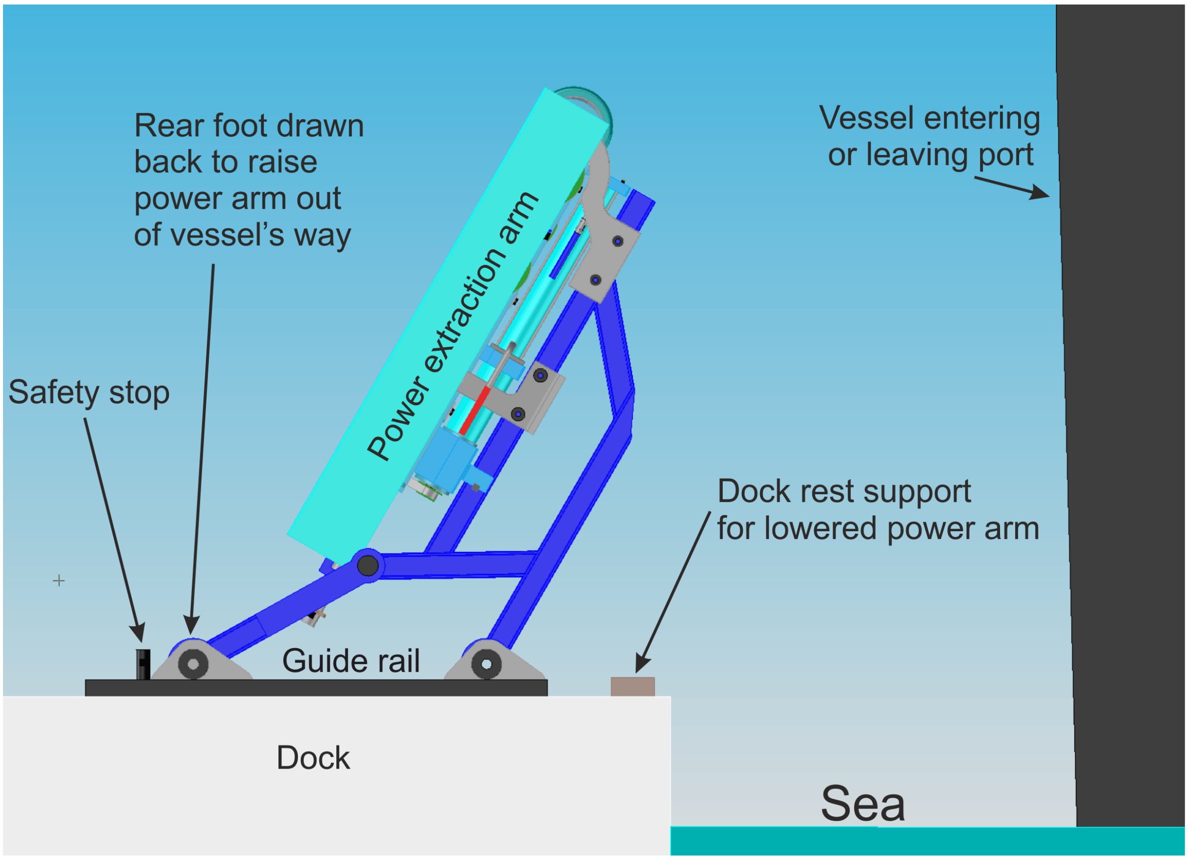

Fig.3: The power extraction arm raised to allow freedom of manoeuvre for the vessel.

1.1 Pier-based tidal pump: Mode of operation

The tidal pump's driving power is drawn from the vessel hull as it follows the sea level height change relative to the pier or dock based installation. In order to obtain an adequate level of input power, large docked vessels are used for driving the system. The vessels can be freighters, tankers or container ships, in fact any vessel with a reasonably large tonnage displacement calling into the port to load or unload cargo.

In Fig.4 the power extraction arm is shown with the arm protection cover removed. At the vessel end is the hull drive wheel that is similar to a pneumatic motor car wheel. The tyre is a standard high friction radial designed for low speeds. The tyre load is not excessive because the drive will be largely dependent on the frictional resistance of the tyre material.

Due to the probability that a very high torque will be imparted by the docked vessel, it has been decided to avoid the sole use of fixed drives such as linear gear drives and gear boxes, where a single tooth must transmit all the load. Instead, a hybrid solution is proposed combining pulley drives and a uni-directional gearbox. The linear motion provided by the tidal height change is converted into rotary motion by the main drive wheel and amplified via a pulley system as shown in Fig.4 and Fig.5. During this phase the torque decreases substantially on passing from one pulley to the next as the rotation speed is increased. Once the torque has been reduced to a suitable level, the rotation is transmitted to a "small" uni-directional gearbox which converts the two direction rotation to that of a single direction. Thereafter, the rotation speed is further amplified by another set of pulleys. The optimum location of the uni-directional gearbox is dictated by the torque level, rotation speed and technical complication. Low torque and low speed do not require massive construction or sophisticated bearings.

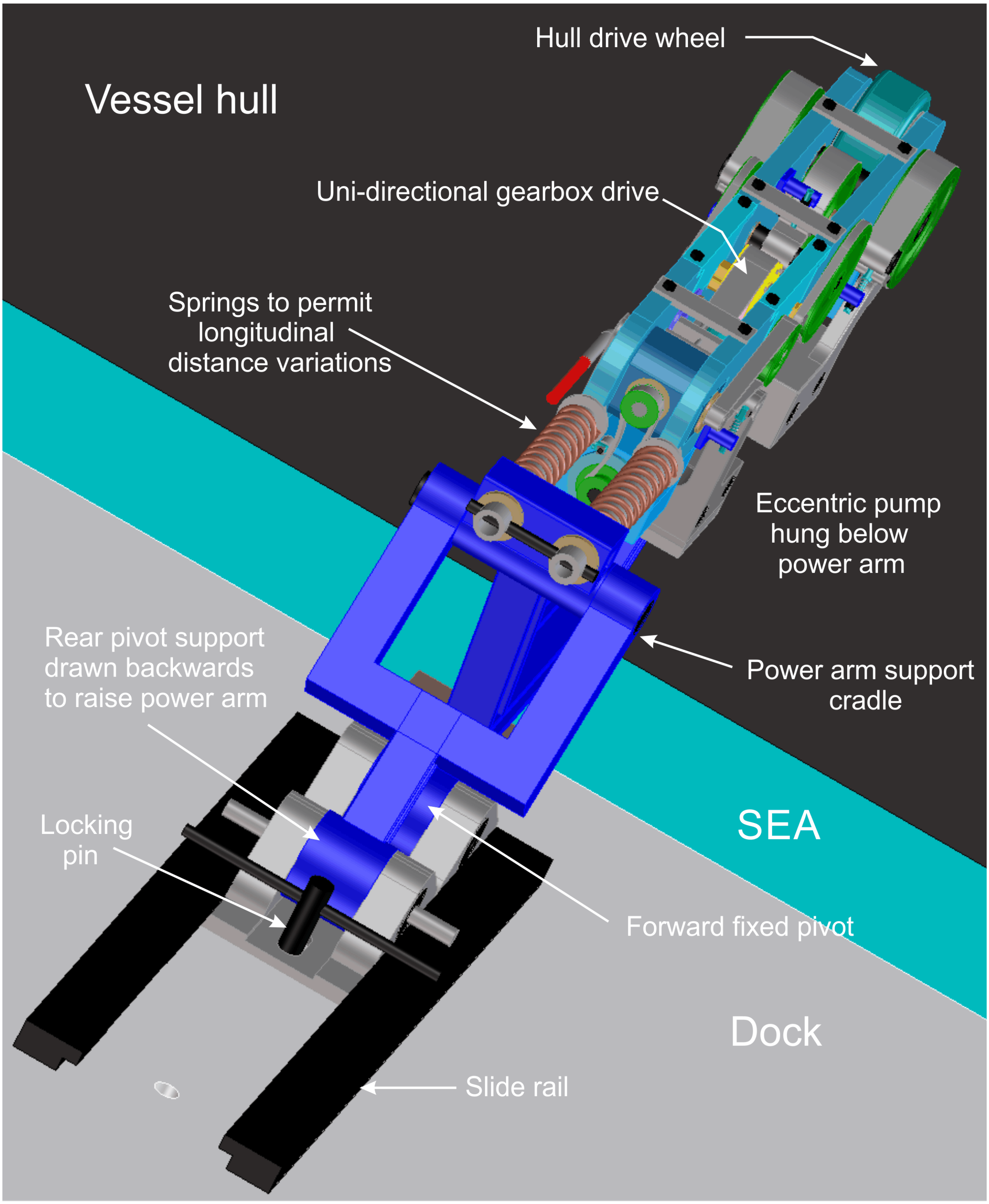

Fig.4: Details of the power extraction arm with the protection cover removed.

In Fig.5 the position of the uni-directional gearbox can be seen relative to the hull drive wheel. The broad drive belt is incorporated so as to prolong belt life. All drive belts can be adjusted.

The locking pin is included so as to prevent the power extraction arm from changing its orientation as the vessel hull moves. This bar penetrates a hole sunk into the dock surface.

The technique for lowering the power extraction arm is to draw the rear foot backwards a few centimetres and then lift out the locking pin. The vehicle used to draw the foot backwards now drives slowly forwards, pushing the rear foot forwards. As the power extraction arm angle decreases, the spring loading will cause the arm to slide forward to the end of its travel and so help bring the whole system down into the operating position. Once there, the locking pin is inserted in the forward dock hole, so locking the tidal pump in its operating position.

The raising of the arm is the reverse procedure, namely the rear foot is drawn backwards a few centimetres and the locking pin withdrawn. The towing vehicle then carries on pulling the rear foot until the power extraction arm is raised to the required angle.

The weight of the power extraction arm will probably override the spring pressure. In order to avoid the power arm sliding completely backwards, so risking conflict with the supporting cradle, a safety stop pin is inserted on the inboard side of the power extraction arm cf. Fig. 5a.

Slung under the power extraction arm, parallel to it, is a low speed eccentric pump. In order to achieve this orientation it is necessary to turn the drive through a right angle via a suitable gearbox drive.

The rotation speed is geared up to suit the requirement of this eccentric freshwater pump. The speed has also to be matched to the pump’s torque requirement. In clarification, increasing the rotation speed is achieved at the expense of torque. This means that an optimal operating region will exist for a specific power extraction arm.

From a technical point of view, higher rotational speed equates to a smaller eccentric pump, and consequently substantially reduced sizing. Under optimal conditions it may be possible to replace the eccentric pump by a centrifugal pump.

A plastic cover is mounted over the power extraction arm so as to protect the unit from birds. Seagull droppings are not optimal for machinery function. It might also be wise to place a protective hat over the hull drive wheel when the unit is raised and not in operation.

At the hull end of the arm it is necessary that the hull drive wheel maintains a good grip on the vessel hull. This would suggest that the wheel could strip paint from the vessel hull. One possibility for overcoming this would be an attachable rubbing strake.

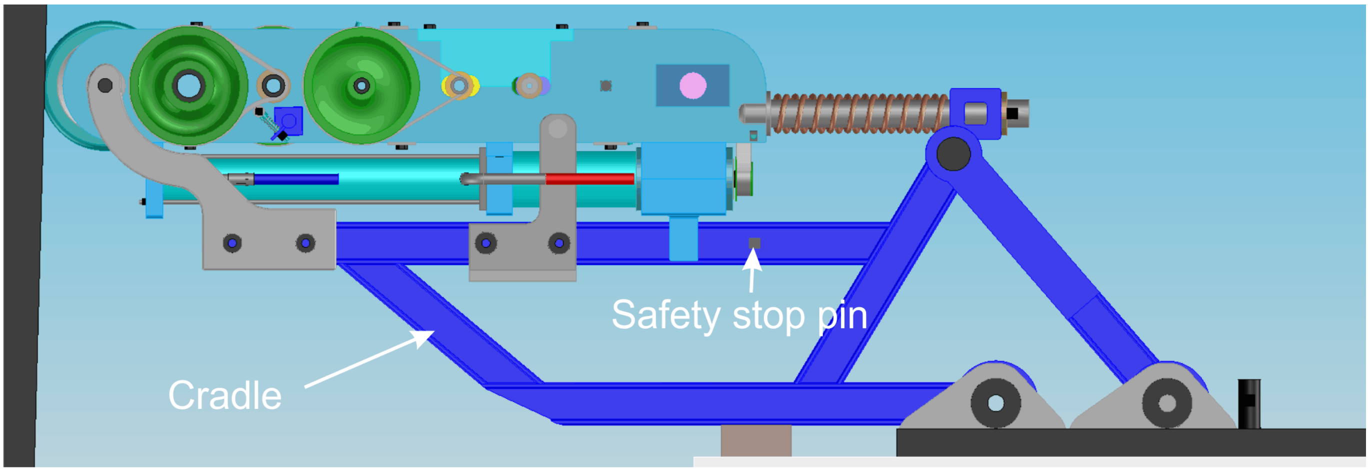

Fig.5a: Operational view with protection cover removed

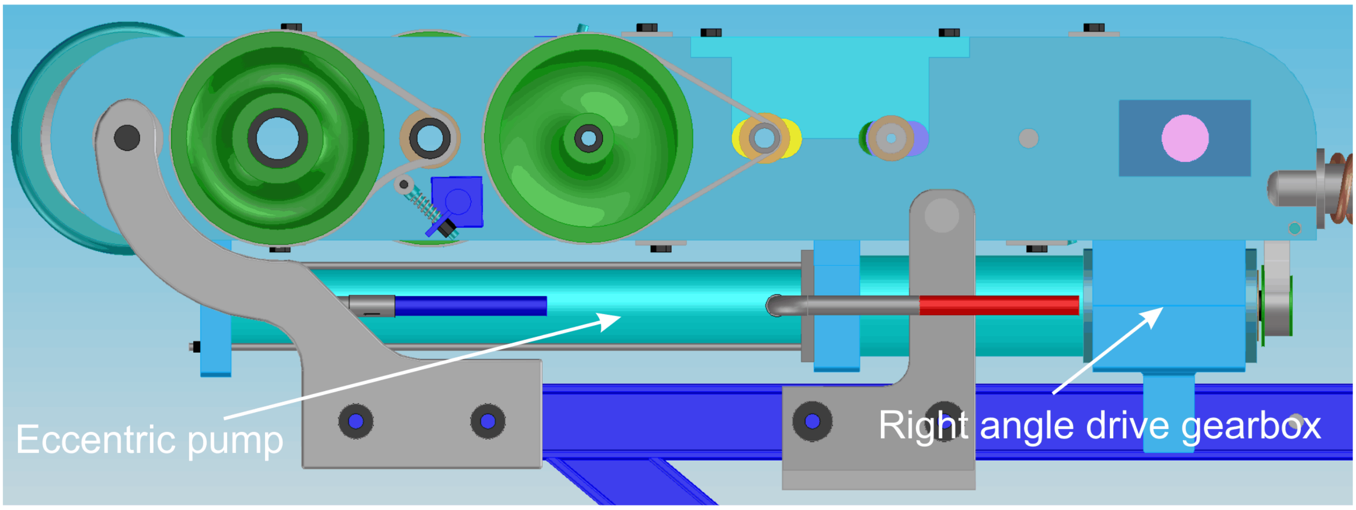

Fig.5b: Operational view with protection cover removed: Detail

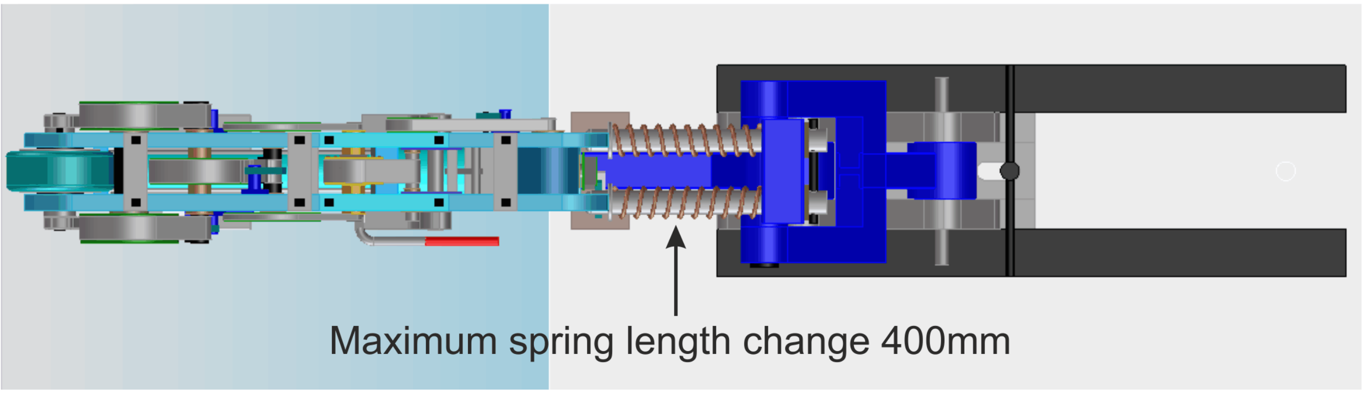

Fig.5c: Aerial view with protection cover removed

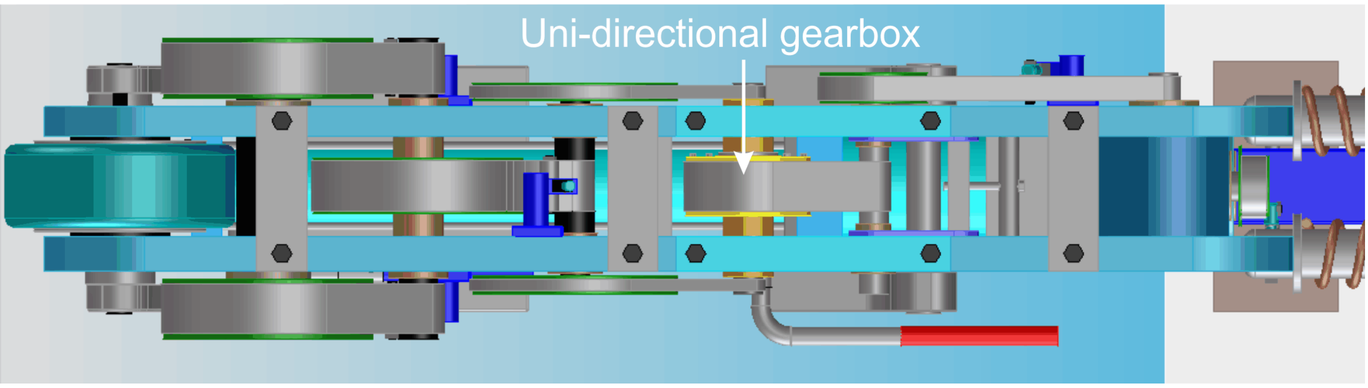

Fig.5d: Aerial view with protection cover removed: Details

Fig.5: Operational and aerial views of the power extraction arm

The eccentric pump is coupled to a pipe work arrangement that includes two one-way valves as shown in Fig.6. The one-way valves prevent pressure and water loss within the main reticulation system if the tidal pump is not in use or stops functioning.

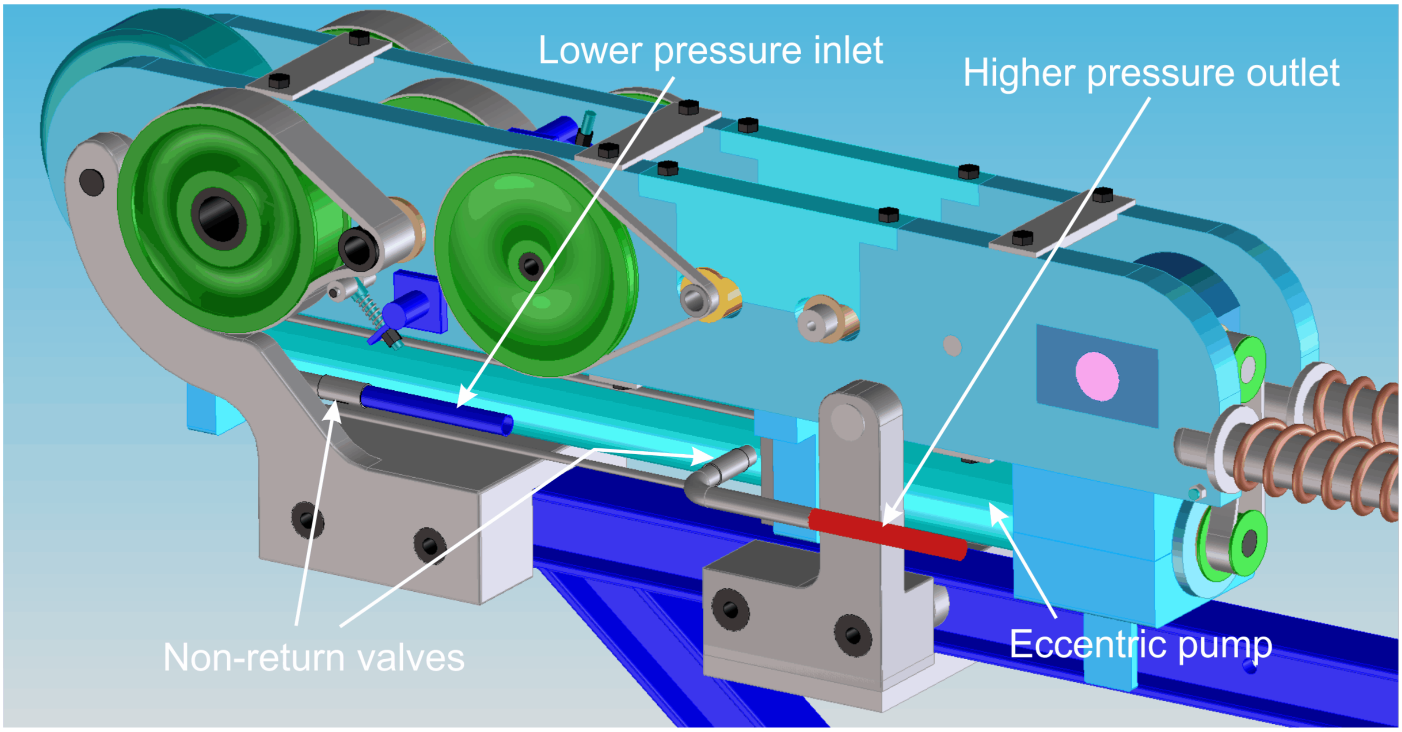

Fig.6: Eccentric pump pipework arrangement

The feed for the eccentric pump enters through the lower pressure inlet and leaves, after pressurisation, via the higher pressure outlet. The two pipes are connected via flexible hoses to separate reticulation pipes that run to and from a remote turbine hall as shown in Fig.1. Within the turbine hall the pipes are connected to an SPC. This new device, SPC, is added so as to create a “closed” pressurised system. In other words, the pump output volume, once the power has been extracted, is returned to the pump inlet still partially pressurised. Consequently, a clean circulation liquid may be employed so avoiding contamination, corrosion, and the requirement for the use of sophisticated materials.

1.2 Discussion: Eccentric pump shaft speed requirement

At present, it is envisaged that a standard production eccentric pump will be used. Of those that are available, a minimum pump shaft speed of 50rpm is required. However, such pumps tend to be voluminous and capital intensive. On increasing the available rotation speed to more than 100rpm, smaller and more efficient units are available. On accepting physical and mechanical compromise, the tidal drive system has been designed so as to achieve a theoretical pump shaft rotation speed of approximately 1,476rpm, assuming a mean tidal height change rate of 1cm/min. This shaft speed from such a small tidal height change rate necessitates a substantial gearing up, namely a multiplication factor in the region of 23,185. Physically, this may not be possible with current commercial components. Experiment will rapidly establish the bounds of reality for the gearing up.

1.3 Specific dimensions of a tidal pump for 400 ton vessel

The CAD drawings presented in this document relate to a tidal pump designed to cope with a 400 ton vessel. Referring to Fig. 4, the diameter of the driving wheel complete with tyre is 460mm. The derivation of the respective drive shaft dimensions to cope with a final pump delivery of 2.45 l/sec at a pressure of 5 bar involve the considerations of Annex A.1. A safe material shear stress load of 300N/mm² is assumed, such as can be obtained from mild steel.

2. Single tidal pump–storage–power generation circuit diagram

Typically, two reticulation lines link the tidal pump to the SPC. The higher pressure line, which runs at approximately 10bar, conveys the tidal pump output to both the SPC and the upper storage reservoir as shown in Fig.7. The lower pressure line at 5bar is the return line and acts as the pump inlet supply. The SPC both recovers an equal quantity of water from the lower reservoir to that pumped to the upper reservoir, and pressurises the input to that of the lower pressure line.

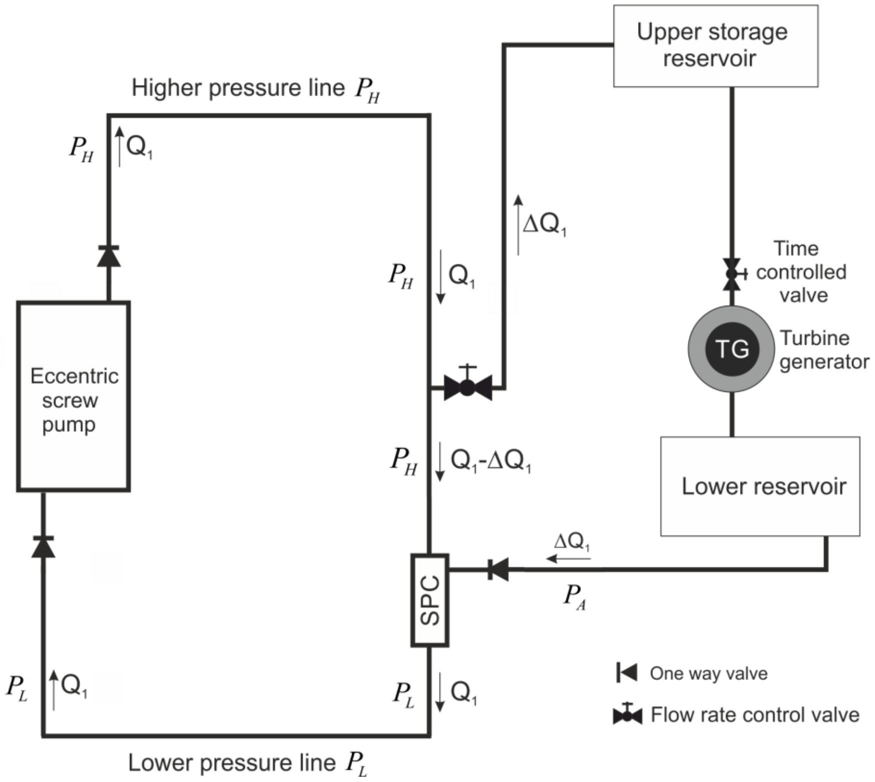

Fig.7: Single tidal pump/storage/power generation circuit diagram

Referring to Fig.7, it should be noted that P_A represents atmospheric pressure and

$$\left.\begin{array}{lll} \text{Higher pressure } P_H > P_L & \text{Lower pressure } \; P_L > P_A & \text{SPC applied inlet pressure} = P_A \\ & \text{Principle flow rate} = Q_1 \qquad \text{SPC suction flow rate} = \Delta Q_1 < Q_1 & \end{array}\right\} \tag{2.1}$$

In order to generate electrical power, the ''Time controlled valve" is open and water from the upper storage reservoir is exhausted through the turbine generator to the lower reservoir. Once the electrical power requirement has been satisfied or the upper storage reservoir emptied, the valve is closed. This system renders the electrical power generation independent of the tidal power energy generation. The tidal pump and associated circuitry supplying the upper reservoir run at the varying rate dictated by the tide, whereas the electrical power generation is dictated by consumer demand.

It should be noted that the SPC suction rate ΔQ_1 is strongly dependent on the SPC applied inlet pressure P_A. This phenomenon is a special characteristic of the SPC. In the present document it is assumed that this advantage is not exploited and that P_A is atmospheric pressure.

2.1 Compact turbine shed

Within the turbine shed, there is an arrangement comprising a reservoir, a turbine generator and the SPC. Figures 8 and 9 are CAD images where the reservoir is rendered translucent.

On the right in Fig.8, mounted on top of the reservoir (tank) and shown in black, is the turbine generator. The large internal tube on the left in Fig.9 is the turbine exhaust tube. On the right in Fig.9, within the tank, is the SPC device shown in pink. The tank is at atmospheric pressure.

The hydraulic flow created by the eccentric pump, Fig.7, is conveyed to the pipe marked with a red end in Fig.8. This hydraulic stream is used to power both the SPC and the turbine. The SPC raises the system pressure in the return pipe marked in blue, Fig.8. This increase in pressure effectively creates a higher delivery pressure to the turbine. A discussion describing the SPC characteristics is presented on the SPC-Tidal website http://www.spc-tidal.co.uk/.

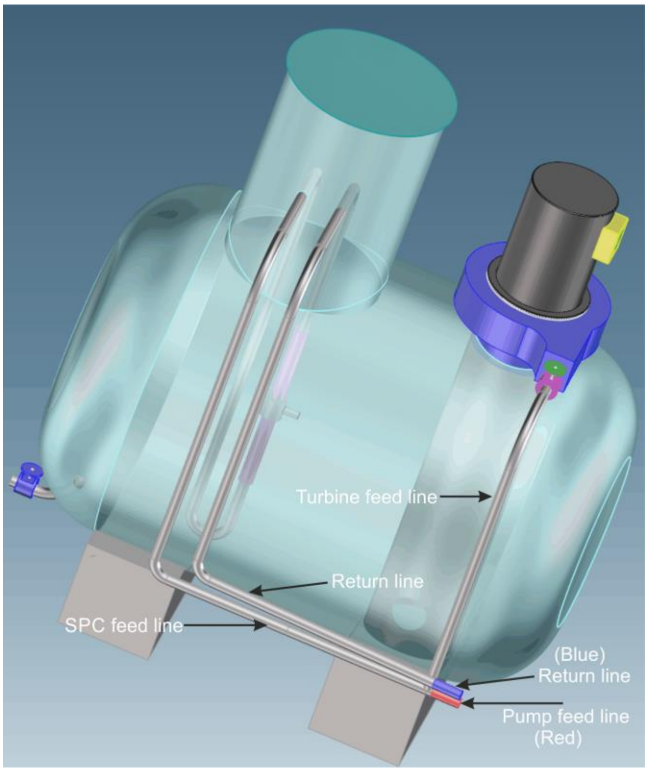

Fig.8: Turbine shed lower reservoir (one of many options)

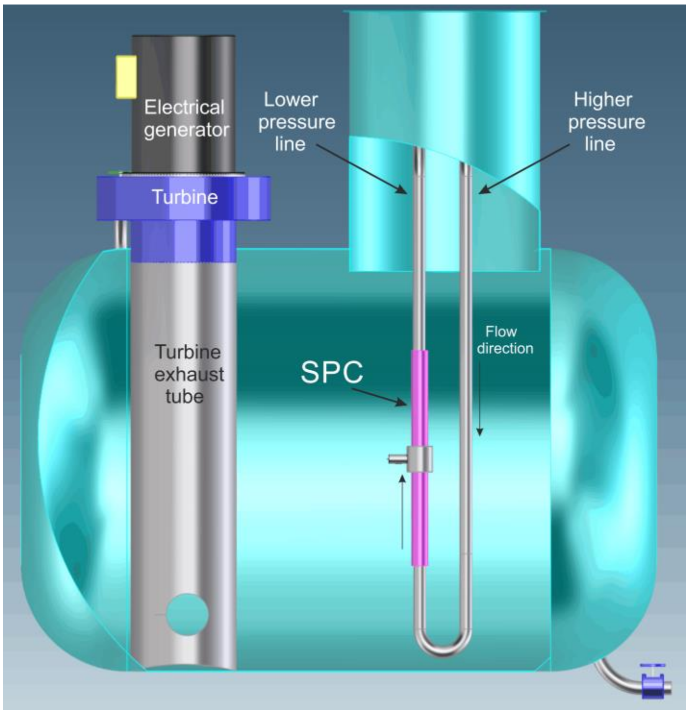

Fig.9: Reservoir cutaway showing the SPC

3. Multiple tidal pump feed with storage supplying a turbine hall

Fig.10 presents the flow diagram for a multiple pump system. In theory, it is not necessary that all the pumps are operative. Each pump is isolated from the network when not operative due to the arrangement of non-return valves. The multiple pumps are linked to the turbine hall by a single pair of supply lines. Within the turbine hall is an SPC, an electrical power generating turbine and two flow rate control valves. External to the turbine hall are the upper and lower reservoirs.

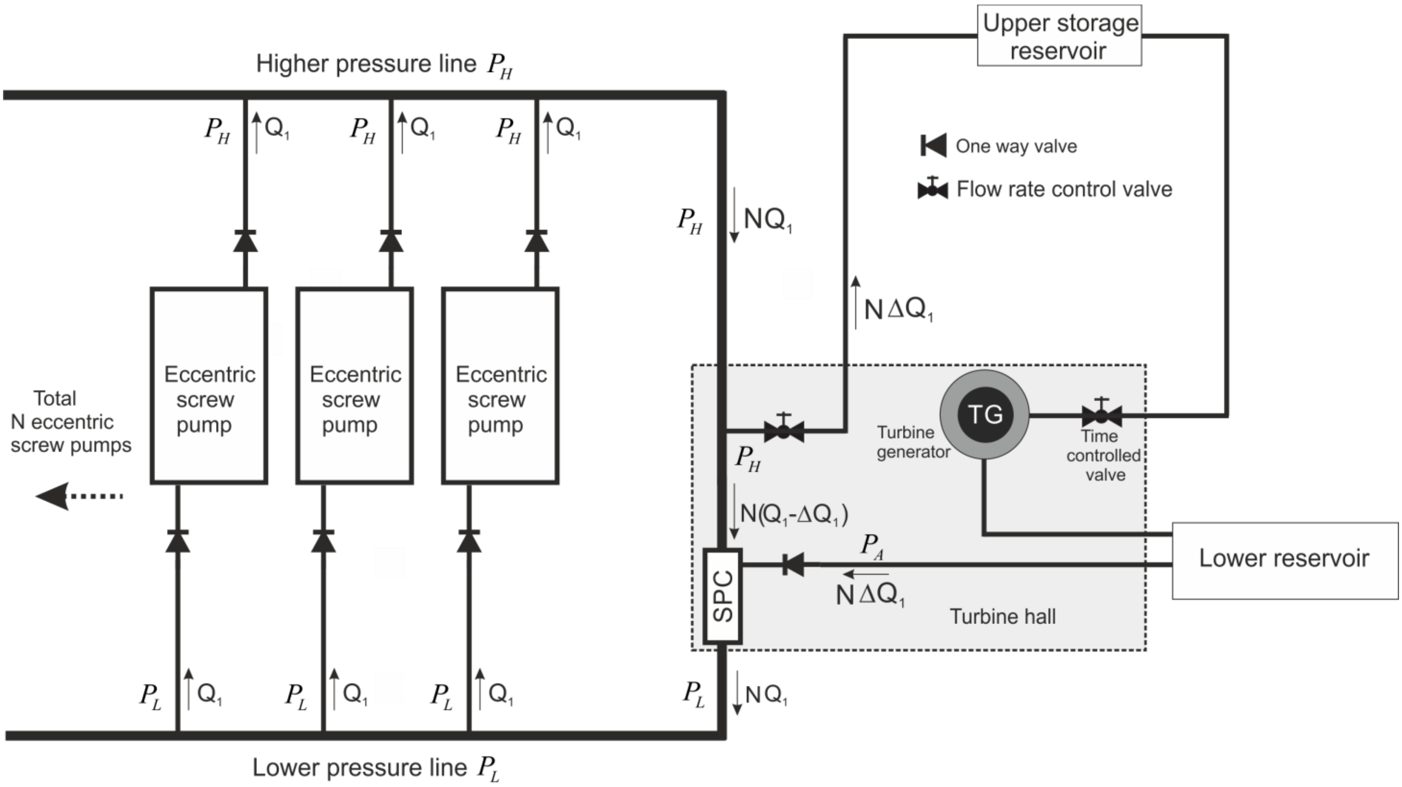

Fig.10: Circuit diagram displaying tidal pumps feeding a storage reservoir coupled to a remote turbine hall

The tidally driven eccentric screw pumps (ESP) deliver their output to the turbine hall. The larger portion of this output drives the SPC which creates and maintains a significant pressure in the low pressure line. The consequence of this is that the delivery pressure of the ESPs is seriously increased. In fact, the ESP delivery pressure can easily be doubled. Some 20 to 30% of the volume output of each ESP is pumped into the upper storage reservoir. The SPC progressively empties the lower reservoir, automatically compensating for the water fed to the upper reservoir. No control system is required as all is fluid dynamically[2ii] self-regulating. One SPC can cope with a substantial throughput.

Once the peak demand period is reached, the time controlled valve is opened and the turbine generator is run at full power for the required period. At the end of the electrical power generation, the time controlled valve is closed. Throughout the whole process, the functioning of the ESP and SPC remains unchanged, being unaffected by the period of electrical power generation.

3.1 Storage reservoirs

The storage reservoirs would not necessarily involve major civil engineering. For limited power production, reservoir tanks can be used. In the case where a river is available, the lower reservoir can in fact be the river.

Another procedure, such as is used in some advanced western countries, is the use of upper and lower drinking water reservoirs. There is virtually no waste of water as the descending drinking water is returned to the upper

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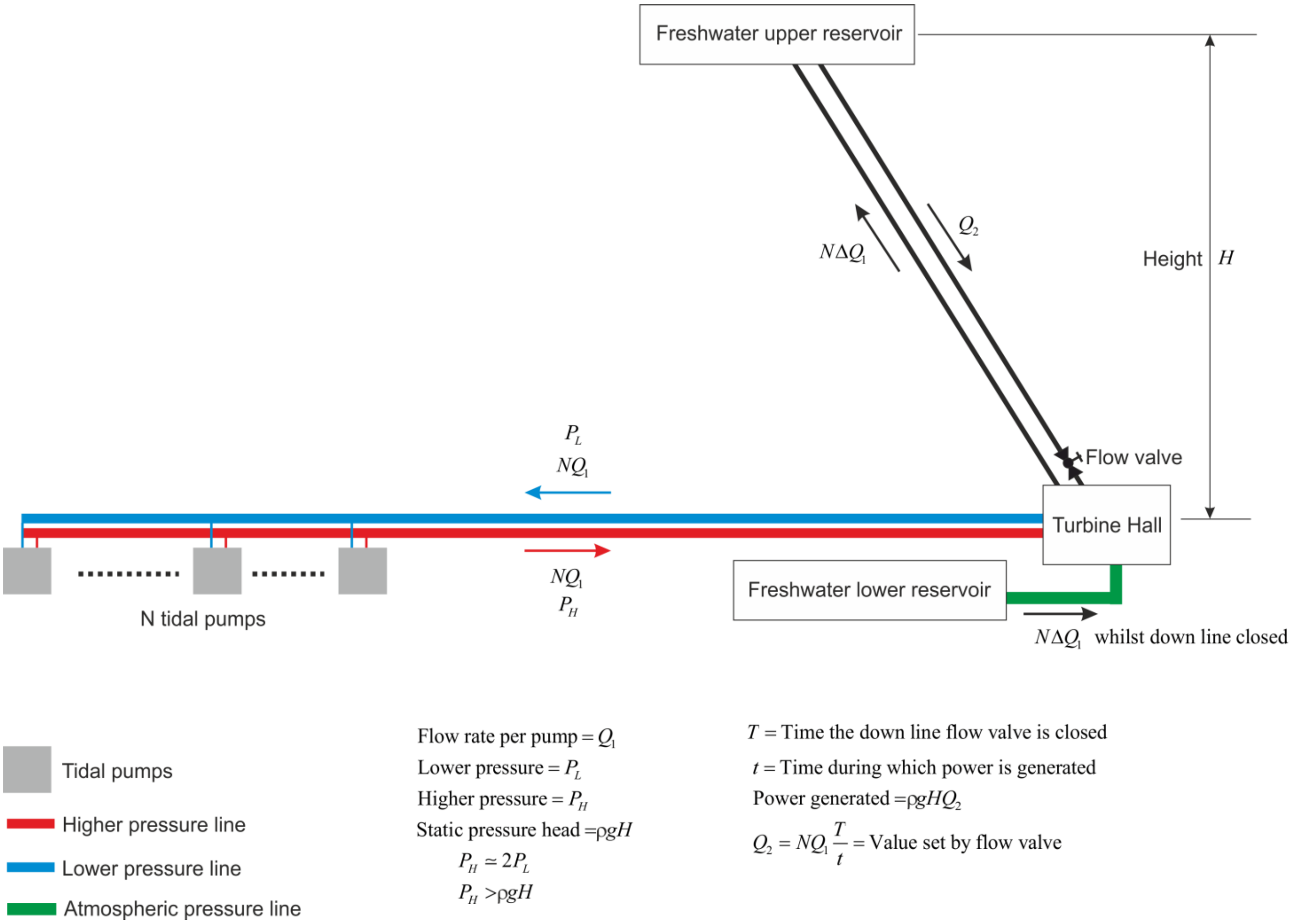
[2] See note under Footnotes

reservoir, following power generation. In fact, the only make-up water required will result from gland leaks and evaporation. A sketch of this concept is shown in Fig.11.



Flow rate per pump $= Q_1$
Lower pressure $= P_L$
Higher pressure $= P_H$
Static pressure head $= \rho g H$
$P_H \simeq 2P_L$
$P_H > \rho g H$

$T =$ Time the down line flow valve is closed
$t =$ Time during which power is generated
Power generated $= \rho g H Q_2$
$Q_2 = NQ_1 \frac{T}{t} =$ Value set by flow valve

Fig.11: Recycling Freshwater between an upper and lower reservoir. Serves both electrical power generation and potentially pressurising a mains water supply.

3.2 The added value of storage

Most renewable energy sources draw their power from either erratic or solar sources. Even the solar source switches on and off as a function of cloud cover and definitely does nothing during the night. These renewable energy sources may be likened to a politic of “take it or leave it”. This is especially so, at present, as there is a lack of convenient energy storage systems.

The tidal energy source is fundamentally different in that it can supply energy at a low level, but virtually continuously. This opens the door to integration techniques and imaginative management. One can profit from this low but reliable energy source by accumulating energy in a storage reservoir and then utilising this energy purely during peak demand as dictated by man’s requirement.

4. TPGU performance

Initially, the efficiency of the tidal pump will be taken as 20% and the electrical conversion 50%. Using the terminology of Fig.11, the results of Annex A.1 and assuming that ΔQ_1 is only 20% of Q_1, one obtains the following performance table:

Electric energy generation	T	t	H	Q_1	ΔQ_1	Q_2	Vessel mass	Tide rate
kWh/day	hr	hr	m	l/sec	l/sec	l/sec	ton	cm/min
6	24	1	100	2.5	0.5	12	400	1
60	24	2	100	25	5	120	4,000	1
120	24	4	100	50	10	240	4,000	2

Table 2: Tidal power generation performance with integrated storage

The efficiencies assumed in deriving the results of Table.2 are as follows:

Eccentric pump	50%	Eccentric pump	50%
Power arm	40%	Power arm	40%
SPC	20%	SPC	20%
Global hydraulic efficiency	4%	Hydraulic/electrical conversion	50%
		Global electrical efficiency	**2%**

Table 3: Break down of component efficiencies

Clearly, the concept appears to have a very low overall efficiency, namely 2%. Generally, such a low efficiency can be improved very rapidly to at least 10%. At this level the daily production for a 1000ton vessel would be 75kWh.

In Table 1 no accreditation is given for any potential gain due to mains water supply pressurisation. The 4,000 ton vessel, with an average tide rate of 2cm/sec, produces the equivalent amount of electrical energy as 1,000m² of solar cells operating for 1 hour in peak insolation. The solar cell generation can only be used in the grid following inversion, whereas the tidal generation is already in suitable AC form.

4.1. Pier-based tidal power pump arrangement footprint

For a pier-based tidal power pump arrangement capable of operating with a 1000ton vessel, the pier footprint and estimated weight is shown in Fig.12.

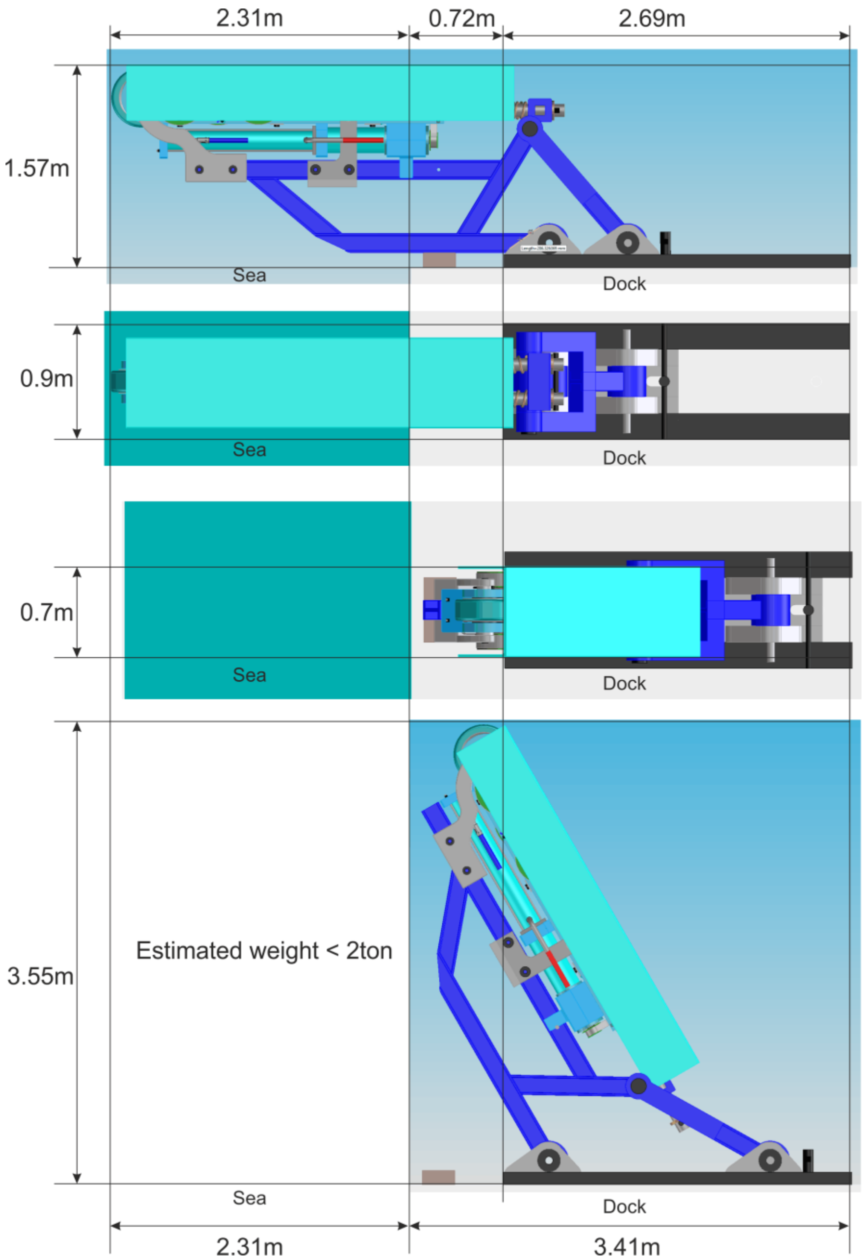


Fig.12: Tidal pump footprint for use on vessels up to 400ton displacement.

The footprint for an arrangement capable of coping with a 5000 ton vessel is thought to be no more than 10% larger. The weight will likely double to 3 tons.

5. Environmental impact including operational dangers

Apart from the turbine generator, the entire system represents no noise[3][iii] pollution at all. The creeping motion and functioning silence of the SPC means that the unit does not have to be distanced from habitation. The turbine generator, on the other hand, will produce some noise and it is conceivable that several TPGUs could be used to supply a common main, feeding a single large turbine generator located in its own building. This could drastically reduce production cost per unit of electricity.

There is no risk whatever should the system run very low on water or dry[4][iv], there would be simply no output.

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[3] See note under Footnotes

[4] See note under Footnotes

6. System attractions

1. Energy from reliable sustainable source.
2. Energy generation exempt from carbon footprint.
3. No handling or pumping of seawater
4. No direct component contact with sea water. Tidal pump can be produced using unsophisticated materials.
5. All, bar one, of the individual component functions have already been separately proven.
6. Scale-up is purely a question of capital cost and not technical feasibility.
7. The most costly contributor in the energy chain is supplied free in the form of visiting vessels.
8. No logistical restraints associated with vessel arrival and departure.
9. Power stocked in upper reservoir till peak requirement reached.
10. Each component can be developed and refined without the need to build a complete system.
11. Several tidal pumps may be linked to a single turbine hall.
12. It is not essential that each pump is functioning.
13. Energy extraction from drinking water reticulation using integrated tidal energy.
14. During periods of flooding, water can be diverted through the upper reservoir for extended periods so as to produce extra electricity for helping with sea level pumping operations.

7. Commercial viability

It may be stated that for every 1000 ton vessel displacement in a tide changing at the rate of 1cm/min (~3.5m/tide), 15kW of power may be generated. Further, loading during an outgoing tide or unloading during a rising tide could seriously increase this value.

It is not inconceivable, once the TPGU concept is proven, to upgrade the technology so as to cope with accelerative movements that could easily contribute more than the first order linear tidal movement. Many thousands of tons accelerating and decelerating, even over a height of a few mm, represents a potentially attractive source of work.

The storage contribution to commercial viability can only be estimated once the real pumping potential has been established. The point to be made here is that the pump characteristics may be presented in the form of delivery pressure and delivery flow rate. The product of these two parameters defines the power requirement of the pump. The converse, namely power requirement of the pump, does not define the delivery pressure. This pressure determines the maximum height at which the storage may be situated. Even a low pumping rate could be of commercial interest under special circumstances.

The SPC not only creates the possibility of a “closed” circuit operation using, for instance, freshwater, but also introduces the ability to upgrade the delivery pressure of the storage pump. This must also be taken into account when estimating the storage pumping potential and commercial contribution.

The commercial viability for a renewable energy source is necessarily based on non-baseload considerations and as such must be viewed as a multi-dimensional exercise.

In the case of tidal energy, the authors’ view is that it must not depend on subsidies but stand on its own feet as an independent profit making industry. The present proposal is designed to be independent of subsidies and to avoid the risk of altering the power source. This risk becomes real the moment objects are placed in a hydraulic stream. In general, the more that is placed in the flow the greater the risk that the power source will be seriously diminished or even lost.

8. Technical risk factors

The main technical risk factors may be seen as the answers to the following questions:

1. Can an adequate rotational speed be achieved with the necessary torque to drive the eccentric pump?
2. Will longitudinal vessel movement prove to be problematic with respect to tidal pump operational lifetime?
3. Will the hull drive wheel strip paint and/or damage the hull?

9. Proposition

It is proposed that a small scale experimental tidal pump be built, excluding the eccentric pump, so as to ascertain proof of principle concerning the conversion of creeping linear flow at very high torque to acceptable rotation speed accompanied by adequate torque.

The scale of the experimental unit should not be too far removed from the design size presented in this document. If this is done, there will be fewer risks associated with scaling up. The estimated cost of the tidal pump, including the eccentric pump, is of the order of £10,000. This would suggest that an experimental unit, excluding eccentric pump but including instrumentation and the necessary flexibility for design change, would cost approximately £50,000.

Annex A.1: Drive shaft torque and rotation speed evaluation

The shear stress at the outer surface of a load bearing hollow uniform circular shaft will be approximated by the following formula:

$$\tau = \frac{Td_0}{2J_T} \qquad \text{A.1.1}$$

where

$$\left.\begin{aligned}
&\tau = \frac{Td_0}{2J_T} \\
&\tau = \text{ Shear stress} \\
&T = \text{ Torque} \\
&d_0 = \text{ External diameter of uniform circular shaft} \\
&J_T = \text{ Polar second moment of area} = \frac{1}{32}\pi\left(d_0^4 - d_1^4\right) \\
&d_1 = \text{ Internal diameter of uniform circular shaft}
\end{aligned}\right\} \qquad \text{A.1.2}$$

This formula is used to size the respective drive shafts required to cope with the torque loads starting at the vessel hull and decreasing progressively as the rotation speed increases. At the pump end of the drive arm one may set the torque requirement as T . For 6 stages of rotation amplification starting at the vessel hull, one obtains the following table:

Rotation amplification stages	Vessel hull	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5	Stage 6
Stage amplification	1	α_1	α_2	α_3	α_4	α_5	α_6
Torque	$\left(\prod_{i=1}^{6}\alpha_i\right)T$	$\left(\prod_{i=2}^{6}\alpha_i\right)T$	$\left(\prod_{i=3}^{6}\alpha_i\right)T$	$\left(\prod_{i=4}^{6}\alpha_i\right)T$	$\left(\prod_{i=5}^{6}\alpha_i\right)T$	$\alpha_6 T$	T
Relative rotation speed	1	α_1	$\prod_{i=1}^{2}\alpha_i$	$\prod_{i=1}^{3}\alpha_i$	$\prod_{i=1}^{4}\alpha_i$	$\prod_{i=1}^{5}\alpha_i$	$\prod_{i=1}^{6}\alpha_i$

Table A.1: The development of the relative torque and rotation speed for each stage. Friction and slip losses are not taken into account.

The idea behind this table is that of suitably scaling the various drives so as to cope with their respective torque requirement. The design presented in this document is based on the following considerations:

Assuming a pump efficiency of 50% and a delivery of 2.45l/sec at 5bar, the pump shaft power requirement is 2.45kW. On achieving a pump shaft rotation speed of 1,476 rpm the required pump shaft torque would be 15.85Nm. The corresponding torque at the vessel hull is 367,505Nm, which may be written as approximately 37 ton metre. The hull drive wheel in the current power arm has a diameter of 46cm and so the vessel displacement must be at least 161 ton. Allowing for a power arm efficiency of 40%, the required vessel displacement is about 400ton. The overall 40% power arm efficiency represents 86% efficiency at each stage of rotation amplification. For this result the following values of α_i have been chosen:

$$\left.\begin{aligned} \alpha_1 &= 3.54 \\ \alpha_2 &= 5.33 \\ \alpha_3 &= 8 \\ \alpha_4 &= 8 \\ \alpha_5 &= 4.80 \\ \alpha_6 &= 4 \end{aligned}\right\} \quad \prod_{i=1}^{6} \alpha_i = 23{,}185 \tag{A.1.3}$$

Footnotes

(i) The new theory was developed by one of the authors during a period of 22 years in Bern University, Switzerland. The fundamental research was aimed at throwing light on some of the strange diseases affecting the cardiovascular system. In 1999 a University technology transfer was carried out and a new company founded so as to exploit some of the practical aspects of the research. The new company had amassed more than 140 full patents by 2009. The new devices, tested during long periods, included deep well pumps, seawater desalination, water purification, high pressure hydraulic pumps, and energy extraction from water currents.

(ii) The SPC is entirely self-regulating. The pressure that it will create in a system is determined by the driving throughput and back-pressure. The higher the back-pressure the greater the throughput that can be achieved.

(iii) Slow speed eccentric pumps don’t normally present a noise problem. However, they can be “lumpy”.

(iv) The SPC will pump multiphase fluids. If liquid is no longer available at the inlet then it will pump and compress gas. On closing the inlet, the SPC functions with zero risk of exploding or rupture. This is not the case for a high pressure pump.