PRO-TIDE

FINAL REPORT

SAUNDERS ENERGY LIMITED

"PowerFrame" development and deployment in River Arun, West Sussex, UK

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Investing in Opportunities

This project has received European Regional Development Funding through INTERREG IV B.

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1. DOCUMENT CONTROL

Version	Date	Who	Details
1	07-10-15	NG	Draft contents and format for discussion.
2	06-11-15	AS	Update as per Jim Fawcett e-mail 20-10-15, and other updates
3	16-11-15	AS	Minor corrections, added Eco report for Arun as Appendix
4	17-11-15	AS	Transferred from SEL template to Pro-Tide template

2. CONTENTS

3) Summary, including purpose of this document

This document details the journey that Saunders Energy Limited (has taken in delivering its first commercial micro tidal device and the results of its 2 year period of testing and developing the technology.

What is PowerFrame?

The unit is an innovative micro hydro-kinetic, zero-head generator. Essentially it's a turbine that turns tidal power and fast water in flowing rivers into electricity. The first model for commercial sale is PowerFrame.

PowerFrame's unique selling points are that it is easy to install without large scale capital works, it is simple yet efficient, robust, and reliable and it's simple to uninstall and service as necessary. It uses a state of the art generator and the innovative application of techniques used in the oil industry to improve mechanical resilience. PowerFrame has been licensed for installation at 5 locations in the South of England and has satisfied all regulatory and environmental requirements.

We believe there is a market for several thousand such machines in the UK alone.

PowerFrame has been subject to academic review by specialists from Sussex and Southampton Universities and has patents in application on aspects of the design.

The journey.

The turbine is the brainchild of Alan Saunders who began testing models in 2009. Saunders Energy Ltd (SEL) was formed as a Company in 2011 and in 2013 raised £45,000 from a small group of investors to take the design concept to market. That process was not as straightforward as planned. Following market research a design concept was established – "PowerTube" - and by early 2014 SEL had constructed a full size test rig and throughout the year tested the unit in both Littlehampton and Chichester Harbours where there are good tidal flows. During this period, we refined our design and made adjustments to ensure our impact on the environment was minimal whilst remaining viable as a commercial generator of electricity. We joined the Pro-Tide Project as a sub partner of the Isle of Wight Council.

Having become confident of the power such a unit is capable of generating, SEL has designed and built the first Production model, a simplified variant of teh original concept: "PowerFrame". In mid 2015 SEL opened its manufacturing facility in Littlehampton and currently employs 3 people full time and 2 part time. This first marque will create commercially viable quantities of electricity in tidal and run of river circumstances without requiring a head of water. Subsequent marques will increase the efficiency of the design and its commercial attraction.

Our technology is complementary to vertical head hydro technology from dams and similar head of water systems, which are well established, and we are able to open a new market for the generation of electricity from tidal and run of river flows at previously unsuitable sites.

We have strong customer interest from the RNLI and a private consortium who are pursuing a long term multiple unit purchasing partnership with SEL, as well early discussions with Community Energy Partnerships in the area and other leads.

We have appointed a Business Development Manager and accepted the services of an expert to help develop business in the third world.

We have financial support from WSCC, through their 'Be The Business' Grant programme and we have been working as a sub partner for the EU Pro Tide Project.

SEL's market research shows that our approach has a lead on the competition and that very large projects are routinely suffering from heavy costs and long development timescales. SEL is in a good position to build a market but we are aware that risks remain.

SEL has developed a strong Board of Directors, MD Alan Saunders, Neil Giles (Chairman), Mark Pratt (Commercial Director), John Bawler (Finance Director). Biographies for each Director are available.

SEL business ethos is to develop a design, development and manufacturing base and supply chain in the Littlehampton area providing skilled work where there is a high level of social depravation.

4) Technology and Product Overview

4.1 The power developed by a fluid flow turbine, whether driven by air or water follows the equation:

$$P = 0.5\ \rho\ C_p\ A\ v^3 \qquad \text{Equation 1}$$

Where:

P = turbine power, W

ρ = fluid density, 1025 kg/m^3 for salt water.

C_p = Coefficient of performance. A characteristic of the machine which encapsulates all the turbine losses, typically between 0.25 and 0.45. A maximum of 0.593 exists which is referred to as the Betz limit. If C_p is set to 1.0 then the power calculated is the power available in the water.

A = area of the turbine swept out as it performs a full revolution through the fluid, m^2. 4.1 m^2 for the turbine test rig and 8.0 m^2 for PowerFrame.

V = the velocity of the fluid, m/s.

4.2 The above is well known and is documented in fluid flow text books. It is derived from the formula for Kinetic Energy, where KE = ½ mv^2. A clear derivation is in a paper from the University of Aarhus, see reference 14.5.

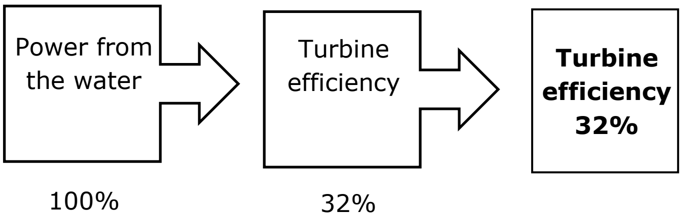
4.3 The turbine blade profile used here have been shown to perform with a C_p of 0.48 by Delft University under ideal conditions. See reference 14.14.

4.4 The electrical power delivered to the grid will be less than the power calculated using equation 1 taking into account losses in the generator and its drive, the inverter and control system and the cabling. In a well designed system these additional losses are of the order of 15-20%.

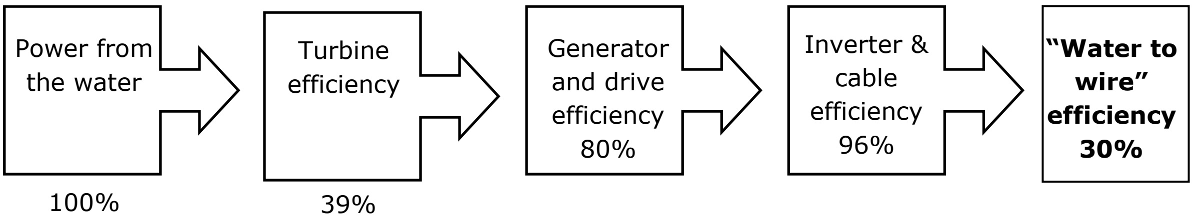
4.5 PowerFrame consists of a horizontal Darrieus turbine with four pairs of blades spaced along the shaft with a generator driven by a speed increasing belt drive. See a full description in the Appendix.

4.6 A study was carried out to understand the sensitivity of the electrical power output to the variables that affect the result. See reference 14.7 "PowerFrame Calculation of Power output Feb 2015 Sensitivity Analysis V2.pdf".

4.7 System diagram showing efficiencies for the turbine test



System diagram showing efficiencies for PowerFrame production unit



5) Design of the turbine test rig and instrumentation

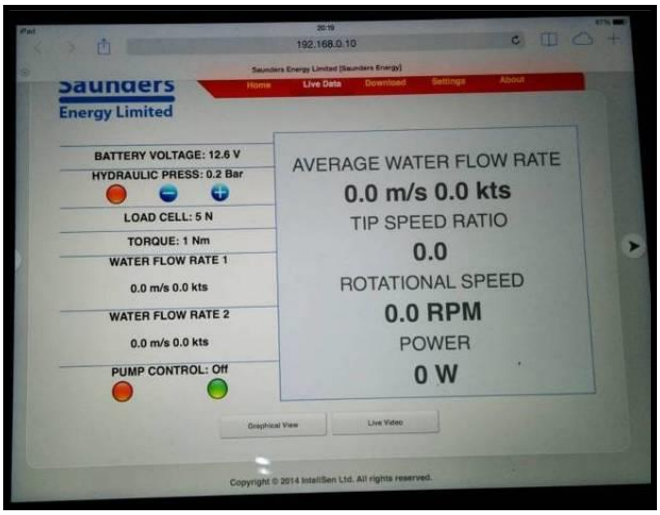
5.1 A turbine test rig has evolved which now represents the intended production configuration of four pairs of blades spaced along a horizontal shaft. Using the European Marine Energy Centre definitions, this has a Technology Readiness Level (TRL) of 6.

Turbine test rig

Double bladed "PowerFrame" configuration

5.2 Sufficient instrumentation was required to record all of the relevant data and to be able to control a dynamometer brake which would allow a braking torque to be applied. They key output is the water flow rate and power output. A data logger was incorporated which included a wireless router so that control and display of the data could be effected by any wifi connected device. See reference 14.8 for the specification of the instrumentation.

5.3 The display of the instrumentation is shown below.



6) Accuracy and repeatability of instrumentation

6.1 Clearly the veracity of the results depends on the quality of the output of the instrumentation. A report was written which studies the accuracy and repeatability of the equipment used. The conclusion is that the measurement of power will be between +0.80% and -0.67% of the true figure. See reference 14.10.

6.2 Thus the reported power figure will be good; however, during operation of the dynamometer brake it was difficult to set the brake so that the turbine was running continuously at maximum power. When too much braking force is applied the turbine stops and the control is not fine enough to give confidence that we are extracting the most power for any given water flow. However, this means that the reported figures are conservative and that any error will result in more power, rather than less.

7) Tests in the River Arun

7.1 A series of five test sessions were undertaken through 2014, from April to December, in the River Arun, Littlehampton, West Sussex.

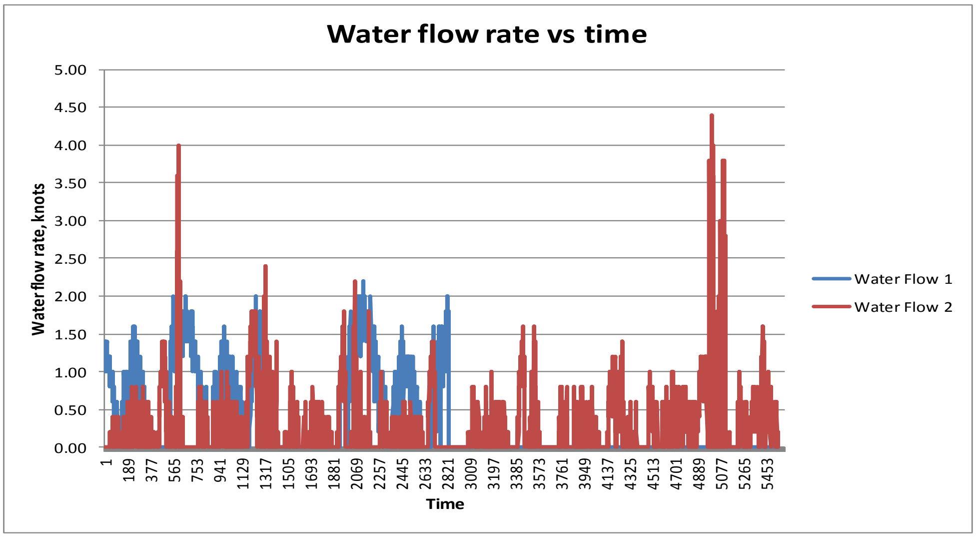
7.2 The first test was carried out alongside a pontoon on the east bank close to the Littlehampton Harbour Board workshop. All following tests were carried out to the western side of the western pier of the footbridge.

7.3 The dynamometer brake was used to apply a torque to the turbine as the water caused it to rotate. The torque was increased until the turbine stalled, at which point the brake was released and the process repeated. Good data was obtained, and analysed in a spreadsheet (reference 14.11). This is shown and discussed in section 8 below. The turbine self-started, ran smoothly and the whole turbine test rig was satisfactory.

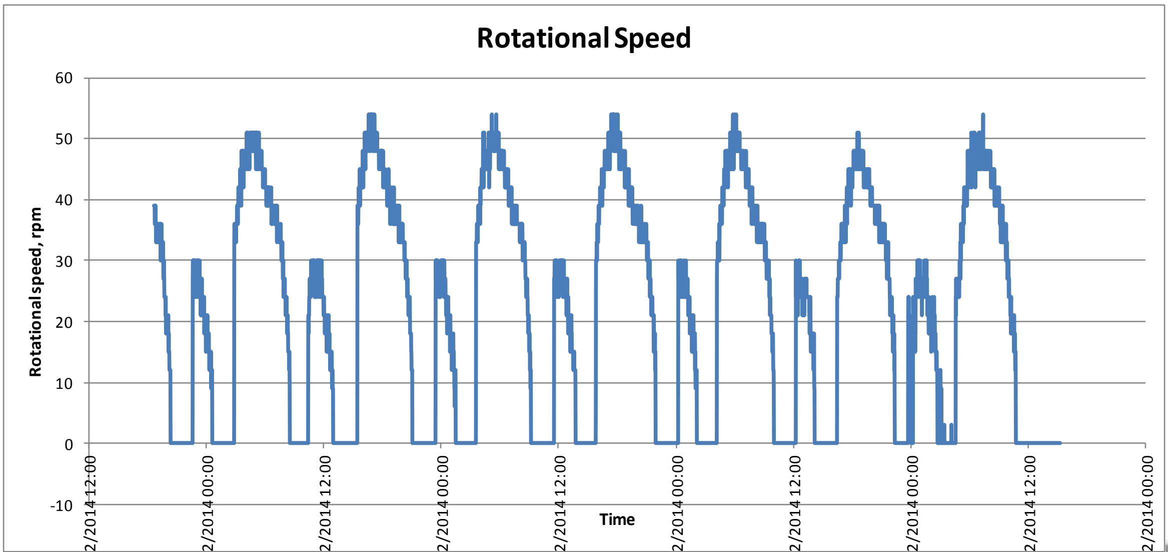
8) Analysis of test data

8.1 The raw data from the data logger was locked into a unique worksheet and copies taken for analysis so that we could always get back to the original data. In this section the relevant graphs from the spreadsheet are shown.

8.2 The data was logged at one minute intervals over the period 23rd December 2014 to 27th December 2014. On the following graph the tide can be seen coming and going over the 3½ day period. Generally, the turbine was left running with the dynamometer brake not applied: it was freewheeling unloaded. It should be noted that two water flow transducer heads are fitted as they are paddle wheel type and susceptible to being stopped by, for instance, weed. It can be seen that one of them stops half way through the period.



8.3 The next graph is the turbine rotational speed over the same period. It can be seen that it stops for a very similar period at high tide and low tide, which is about 2.25 hours. The periods of higher rotational speed are when the tide is flowing out during the ebb tide. The periods of lower rotational speed are when the tide is coming in during the flood tide. This data is for the River Arun and other sites may have particular characteristics. In particular Chichester Harbour entrance is believed to be closer to a sine wave with the higher flow rates holding up for a longer period. See section 10.2. Understanding the local flow rates are essential to being able to predict the amount of energy that will be generated.



8.4 Water flow rate data from a flood tide – ebb tide cycle was used to derive a factor to use to calculate the energy, kWh, generated over the cycle following calculation of the peak electrical power, kW. This factor is calculated to be 0.5 as shown in reference 14.15 "Model of power generated from a tidal curve.xls".

Peak tidal flow rate	4.0	knots
Inlet area	2.25	m2
ea of turbine housing	0.36	m2
Area of turbine	0.31	m2
Generator size	100.0	kW

Notes
1) The power cube law flattens available power at low water velocities.

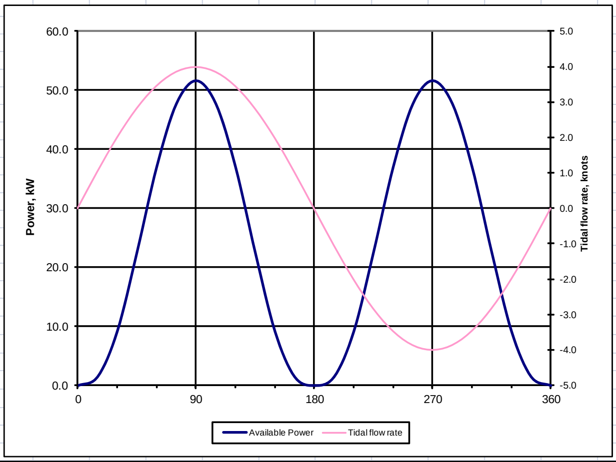
Further Notes
2) The ratio of cumulative power over the 12 hours ~ 0.5 x peak power x 12 hours.
3) To simplify the maths, use 0.5 as a factor when calulating the kWh generated in a tidal flow.
4) Also allow for the spring-neap cycle, which approximates to a halving of the peak flow of a spring tide at a neap tide, whereas the daily cycle stops altogether. For expediancy and simplicity use 0.6 as a further factor.
5) 0.5 x 0.6 = 0.3. It would appear to be about right that a tidal flow would produce about 1/3 of the energy compared to a river running continuously.

Degrees	Sine (degrees)	Open Water speed, Knots	Turbine water speed, m/s	Available Power, kW	Cumulative Available Energy, kWh	Capped Cumulative Energy, kWh
0	0.00	0.00	0.00	0.000	0.000	0.000
15	0.26	1.04	3.16	1.489	0.372	0.372
30	0.50	2.00	5.79	9.180	3.039	3.039
45	0.71	2.83	7.81	22.542	10.970	10.970
60	0.87	3.46	9.21	36.981	25.850	25.850
75	0.97	3.86	10.02	47.681	47.016	47.016
90	1.00	4.00	10.29	51.577	71.830	71.830
105	0.97	3.86	10.02	47.681	96.645	96.645
120	0.87	3.46	9.21	36.981	117.810	117.810
135	0.71	2.83	7.81	22.542	132.691	132.691
150	0.50	2.00	5.79	9.180	140.621	140.621
165	0.26	1.04	3.16	1.489	143.288	143.288
180	0.00	0.00	0.00	0.000	143.661	143.661
195	-0.26	-1.04	3.16	1.489	144.033	144.033
210	-0.50	-2.00	5.79	9.180	146.700	146.700
225	-0.71	-2.83	7.81	22.542	154.630	154.630
240	-0.87	-3.46	9.21	36.981	169.511	169.511
255	-0.97	-3.86	10.02	47.681	190.676	190.676
270	-1.00	-4.00	10.29	51.577	215.491	215.491
285	-0.97	-3.86	10.02	47.681	240.305	240.305
300	-0.87	-3.46	9.21	36.981	261.471	261.471
315	-0.71	-2.83	7.81	22.542	276.351	276.351
330	-0.50	-2.00	5.79	9.180	284.282	284.282
345	-0.26	-1.04	3.16	1.489	286.949	286.949
360	0.00	0.00	0.00	0.000	287.321	287.321

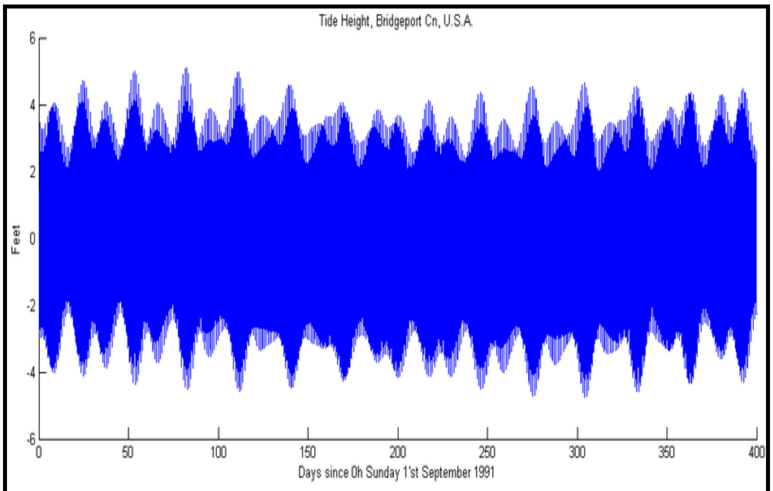
618.930

Ratio of cumulative energy over 12 hours to peak power times 12 hours

0.5



8.5 Similarly, the relationship between spring and neap tides needs to be established. The study of the variation tidal heights goes back hundreds of years, and mathematically is well understood. The associated variation in tidal velocity is analysed mathematically as if it were a tidal height, but out of phase with zero flow at the maximum height and based on the peak flow rate. See reference 14.7.



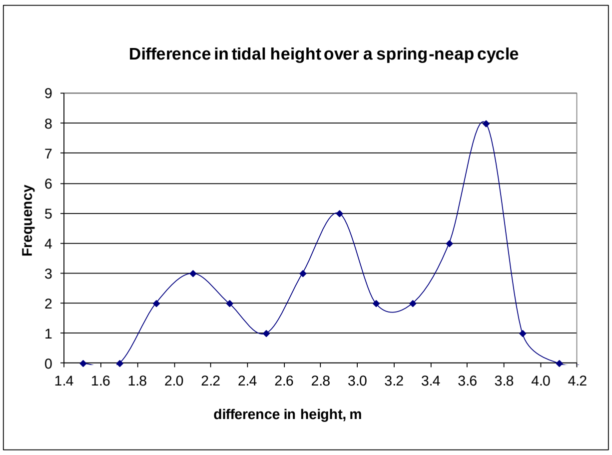
Graph showing typical fortnightly spring and neap tide cycle about a mean level. CH of LHB stated that maximum spring is 6.4 knots and minimum neap is 3.0 knots peak flow (mid-way between tidal extremes.)

The tidal height graph for Bridgeport is often used to demonstrate the variation between spring and neap tides

It is the difference in height from high tide to low tide that determines the velocity. The differences in height over a spring – neap cycle for Chichester harbour entrance were plotted as a distribution. It can be seen that the mean is biased towards the higher values.

In this case the mean, as a proportion of the range is

Mean proportion = (3.0 – 1.8) / (3.8 – 1.8) = 0.6



8.6 For an attended period, the dynamometer brake was applied over several hours as the tide dropped. The method was to gradually increase the brake load, which generates a torque at a known rpm and thus the power can be calculated. Eventually the braking load stops the turbine and the maximum power for that water flow is taken as the previous data point. Reference 14.12 is the data during this dynamometer test period.

8.7 Columns for the torque, power and tip speed ratio have been added to the worksheet.

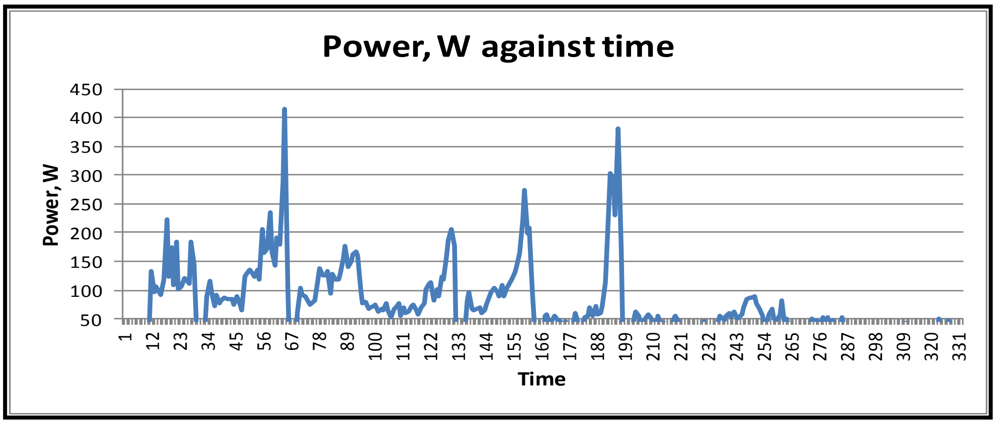
Torque = load cell force, N X torque arm radius (0.14 m), Nm.

Power = torque, Nm X rotational speed in radians/s, Watts.

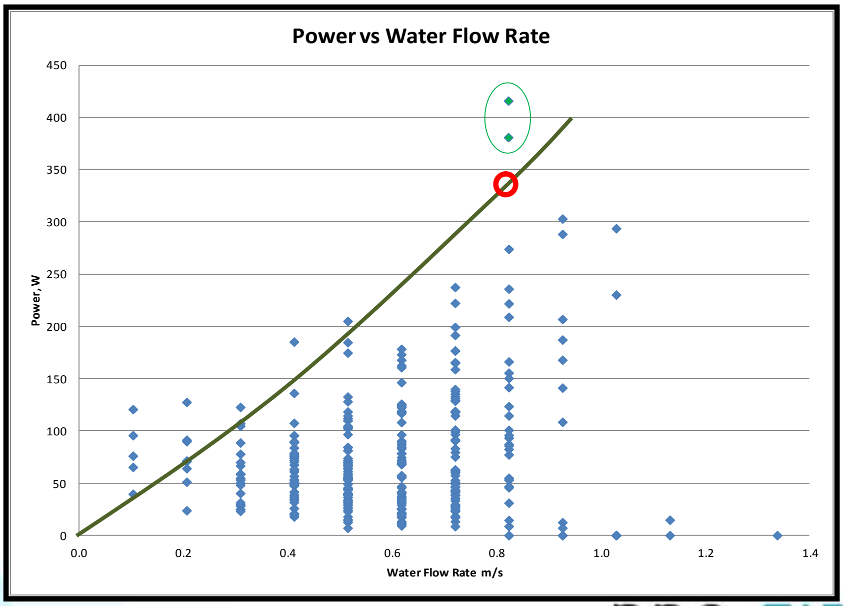
Tip speed ratio = linear turbine blade speed m/s / water speed m/s.

The data was copied to a new worksheet before any sorting or other manipulation was done. There are some interesting graphs on the iDAQ worksheet which set the scene.

8.8 The following graph shows the brake being applied gradually and the power being generated until the turbine is stopped, then the next test begins. Two of the peak power readings are substantially higher than the remainder. Although it is hard to think of a reason why an erroneous reading can be too high, these two data points are discounted when the estimate of C_p is made. See 8.9.



8.9 The data was copied to a new worksheet and sorted by flow rate, a graph of power vs water flow rate was drawn. The two high data points from the graph above are shown in pale green and the line in dark green was drawn on manually to represent a realistic performance curve given the small amount of data.



9) Summary of testing

9.1 A conservative output from the test rig is 340 W at 0.8 m/s

9.2 Rearranging equation 1

$$C_p = P / (0.5 \rho A v^3) \quad \text{Equation 2}$$

$$C_p = 340 / (0.5 \times 1025 \times 4.1 \times 0.8^3) = 0.32$$

9.3 By feeding this back into equation 1 this allows estimates of the power output and by following the method in section 10 below the energy output can be calculated.

10) Prediction of energy output of PowerFrame

10.1 The energy output is the basis for calculating the income for an installation. The starting point is the predicted power output from PowerFrame for a particular water flow rate. The flow rate taken is the peak flow rate at a spring tide and then an allowance made for the cycle from spring to neap tides and for the daily tidal cycle. The calculation here is based on a sinusoidal variation of tidal flow.

10.2 Note that tidal flow is complex and varies according to geographical site, many locations vary from the sinusoidal model, but the variation is expected to be of the order of 10% or so except in particular circumstances. The tidal variation in the River Arun has been shown in section 8.3 not to be a symmetrical sine wave. Each site needs to be considered on its own merits.

10.3 The energy generated over a year is calculated using**:**

$E_{annual} = P_{ep}$ x 0.5 x 0.6 x 24 hours x 365 days kWh per year**.**

Where:

P_{ep} = peak electrical power, kW

0.5 = the portion of the power due to the daily tidal cycle. See section 8.4

0.6 = the portion due to the spring-neap cycle. See section 8.5.

11) Conclusion to test rig tests.

11.1 The figures published in the marketing flyer, reference 14.2, and shown in the table below, have been calculated using a water to wire C_p value of 0.30, which takes into account a proposed improvement to the turbine arising from these tests– see 11.2. It has been assumed that the value of C_p is a constant over the range of water flow rates. Note that in the marketing flyer for PowerFrame 2.5 knots is shown as being equivalent to 1.2 m/s, this should read 1.3 m/s. The calculated figures are for 2.5 knots.

Water flow rate, knots (m/s)	Nominal Power, kW_{e-p}	Estimated MWh/annum (equivalent number of houses)		Estimated annual income*	
		Tidal**	One direction	Tidal	One direction
2.5 (1.2)	2.3	5 - 6 (1.5)	18 (4.5)	Up to £1,500	£4,300
3.0 (1.6)	5.4	13 - 15 (3.5)	42 (11)	Up to £3,700	£10,200
4.0 (2.0)	10.6	26 - 28 (7)	83.4 (21)	Up to £7,200	£20,000
5.0 (2.6)	23	59 - 61 (15)	183 (45)	Up to £15,800	£44,000
6.0 (3.1)	39	100 - 103 (26)	310 (78)	Up to £26,800	£74,600

* Feed In Tariff at 21.12p/kWh for ≤ 15 kWe-p at 1st April 2014 plus export value of electricity at 4.78 p/kWh.

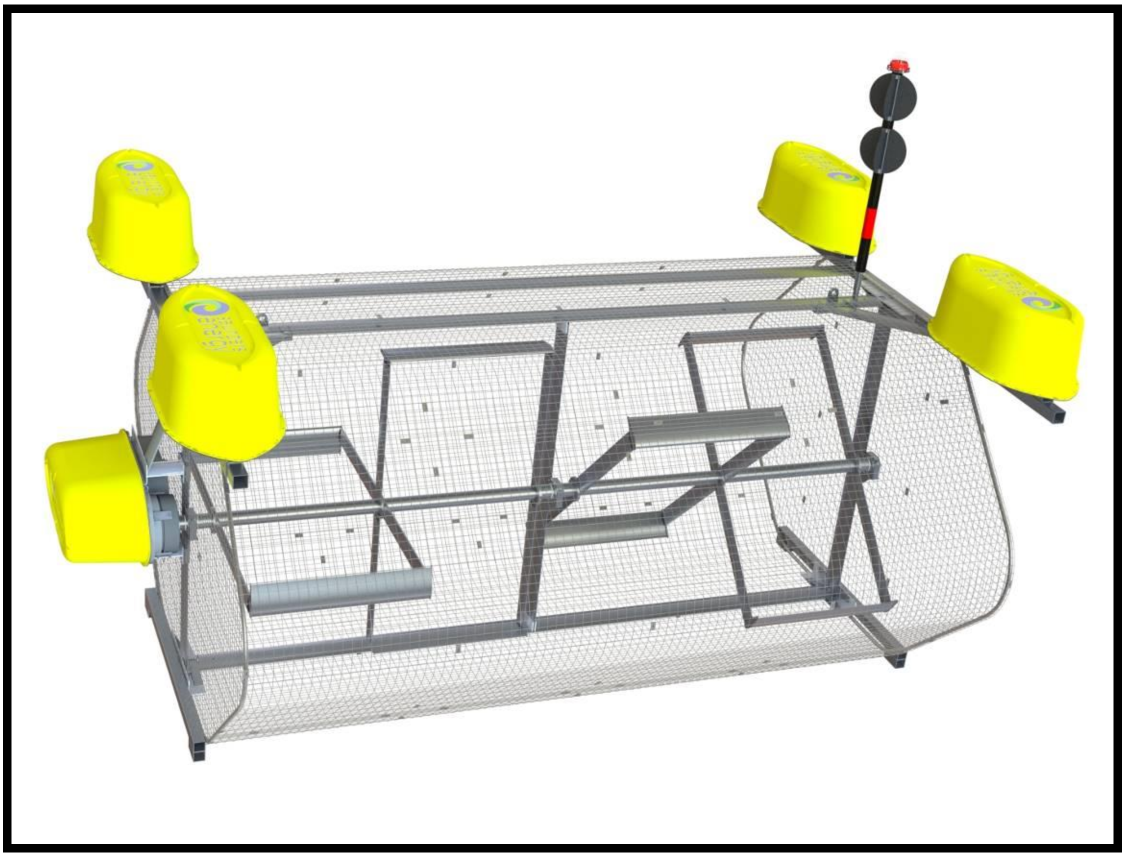
** The energy generated in a tidal site varies according to the relationship between the flood tide and ebb tide, amongst other variables.

11.2 Design modifications to the struts supporting the turbine blades have been made which will reduce the drag as the turbine rotates. The table below is an excerpt from Reference 14.17 and shows that an extra 510W (621W – 111W) is to be expected, bringing the C_p up to 0.39. This brings the water to wire efficiency to 30%, from 26% for the test rig. See the following extract from that reference.

Checked 12-02-15. AS.			TEST RIG		POWERFRAME	
Model as cantilever	**Lyatkher aluminium**	**Steel**	**Aluminium (TEST RIG)**	**BSB 50**	**Aluminium (POWERFRAME)**	**(BSB) 100**
Length of strut	256	930	930	930	2000	2000
Total Bending Moment	6.6	39.3	39.3	39.3	39.3	39.3
Equivalent end force	25.8	42.3	42.3	42.3	19.6	19.6
Width	63	60	60	49	60	98
Thickness	10.0	5.0	6.0	9.0	6.0	18.0
Moment of Inertia	0.53	0.06	0.11	0.13	0.11	2.10
Young's Modulus	69	200	69	69	69	69
Maximum Deflection	**0.0**	**2.1**	**3.6**	**2.9**	**16.5**	**0.8**
Allowable deflection (L/250)	1.0	3.7	3.7	3.7	8.0	8.0
Maximum stress	**6.3**	**157.2**	**109.2**	**134.7**	**109.2**	**16.8**
Material coefficient	0.9	0.9	0.9	0.9	0.9	0.9
Environment coefficient	0.8	0.8	0.8	0.8	0.8	0.8
Application coefficient	0.8	0.8	0.8	0.8	0.8	0.8
Design Stress	**10.9**	**272.9**	**189.5**	**233.8**	**189.5**	**29.2**
Allowable UTS	270	400	270	270	0	270
Weight of strut	0.52	2.18	0.90		#VALUE!	
Speed of water	1.2	1.2	1.2	1.2	1.2	1.2
DRAG						
Sides	**Skin friction**					
Drag coefficient, Cd	0.001	0.001	0.001	0.001	0.001	0.001
Area of one side	0.0161	0.0558	0.0558	0.0456	0.1200	0.1960
Total area	0.0322	0.1116	0.1116	0.0911	0.2400	0.3920
Drag force	0.02	0.08	0.08	0.07	0.18	0.29
On the leading edge	**Form drag**					
Square edge, Cd	1.8	1.8	1.8		1.8	
Circular edge, Cd	1.0	1.0	1.0	0.1	1.0	0.1
Area	0.0026	0.0047	0.0056	0.0084	0.0120	0.0360
Drag force, square edge	3.4	3.4	3.4	0.0	3.4	0.0
Drag force, circular edge	1.9	3.4	4.1	0.3	8.9	1.3
Torque, square edge	0.4	1.6	1.6	0.0	3.6	0.3
Torque, circular/hydrofoil edge		1.6	2.0	0.2	9.0	1.6
Rotational speed			53	53	41	41
Per strut			11	1	39	7
8 blades, 16 struts			173	16	621	111

11.3 These are many influences on these results, not least of which is the variation in the tidal cycle. Whilst a greater degree of confidence can be had by repeating the test with the turbine test rig and generating more power vs water flow rate data, the real test is to run a PowerFrame fitted with a generator over the approximately 28-day spring-neap tidal cycle. (The cycle is virtually symmetrical so running it for 14 days and multiplying by 26 will give a close approximation to an annual figure).

12) Configuration of production model: PowerFrame



12.1 A Product Design Specification was developed for a pre-production prototype of PowerFrame. This outlines the features required and how they are to be achieved. The device can either float or be mounted on the river bed or sea bed. Note that the water flow is faster on the surface. Various means of attaching PowerFrame are covered. The floats can be brightly coloured to aid naigation or be discrete. An Isolated Danger Mark lamp is available as an accessory. The electrical output is connected to the grid in the conventional way via an inverter. The design philosophy is to keep the approach simple and robust as the salt water environment with associated unpredictable wind and occasional boat loadings is extremely tough.

12.2 Using the European Marine Energy Centre definitions, PowerFrame has a Technology Readiness Level (TRL) of 7, which will become 8 after completion of the current test programme.

12.3 The frame is a hydrofoil shaped aluminium extrusion. Using a hydrofoil section substantially reduces the loadings on the attachment method. The means of attachment will vary due to the local conditions at the installation site, and all will be standard marine practice. For mooring in open water a bridle will be attached to both sides from which a total of four steel wires will run from each corner to drilled "duckbill" anchors or similar. Other mooring techniques include steel brackets to a pontoon which itself will rise and fall with the tide, and the use of two vertical columns attached to a river wall, bridge pier or other structure. Brackets attached to the PowerFrame will then ride up and down the columns.

12.4 The frame is a modular design with a central part which supports the bearings and then optional upper and lower frames to stiffen this central frame depending on the target water flow rate.

12.5 As PowerFrame is intended for use in rivers and shallow coastal areas close to shore and floats close to the surface a mesh cage surrounds the turbine in order to prevent swimmers, divers and large fish from entering into the turbine area. In addition, it protects the turbine from collision with logs and other large water borne debris. The mesh has 50 mm x 50 mm openings and is constructed of 316 grade stainless steel. It is electrically isolated from any aluminium components to prevent galvanic corrosion. The effect of the mesh on the turbine performance has been tested and design rules established to prevent any reduction in output.

12.6 The bearings bushes are a conventional water lubricated material and in terms of the loadings have an infinite design life. In practice debris in the water, such as sand and other hard particles, will reduce the life and they are expected to be replaced at five years. A bearing test rig to carry out accelerated testing will be designed and built late in 2015.

12.7 Aluminium hydrodynamic sectioned struts attach the turbine blades to the shaft. The turbine blades have winglets at the ends to increase the performance. The turbine blades and struts are filled with expanding foam to prevent water ingress. Note that all rotating parts are hard anodised to prevent erosion.

12.8 The PowerTube design has a permanent magnet generator fixed directly onto the shaft so that a speed increaser was not required. This is cost effective for the smaller diameter, faster rotating turbine of PowerTube. For PowerFrame where we have no acceleration of the water and the turbine is now a larger diameter the shaft speed is much slower and this route is no longer cost effective. A two stage belt drive speed increaser drives a higher speed, thereby lower cost, permanent magnet generator.

12.9 The speed increaser and generator are contained in a sealed enclosure and the drive to that is via a magnetic coupling, thus there is no shaft seal which would fail at some point in time.

12.10 The method of mooring is very simple. It is based on a standard method used for pontoons. It allows the unit to be quickly attached, and detached, for maintenance and end of life disposal. Experience has shown that the entire process from having the PowerFrame unit ashore, to being picked up by the crane barge, attachment and return to shore takes one hour.

12.11 ENVIRONMENTAL COMPATIBILITY

See reference 14.21, the Marine Management Organisation Licence application.

*This Licence has been issued at the first attempt resulting in a 25-year licence with **no pre-conditions** regarding the effect on the environment.*

This include aesthetics, the effect on marine life, the effect on bird life, the effect on the seabed, pollution and disposal at the end if its life.

12.11.1 Aesthetics. PowerFrame only has its floats above the water surface along with a small electronics enclosure. Colours can be selected to make the unit discrete, or if close to a navigational area the colours can comply with the local requirements.

12.11.2 Effect on marine life. Discussions have been held with the Environment Agency which has informed details of the design. Reports from the use or research into other turbines of this type show that it presents a higher pressure area in the water and fish swimming towards it detect this and avoid it. Evidence from the turbine test rig tests suggests that the water slows down immediately in front of the turbine as it provides a resistance to flow. Thus, there is no "suction" effect which could draw fish towards it. In addition the internal clearances are larger than the mesh openings and the velocity of the turbine blades is relatively low.

12.11.2.1 Recent tests in The Netherlands as part of the Pro-Tide project indicate that this type of mechanism is fish friendly and research by others such as that in reference 14.19.

12.11.3 Effect on bird life. It is possible that the installation sites of PowerFrame could coincide with areas used by diving birds. Surveys prior to installation may need to be carried out. This is a low level risk as diving birds like slow moving water where visibility is good. By its nature, PowerFrame is installed in areas of faster flowing water. A survey carried out as part of the licencing for the River Arun sites gave the "all clear". See reference 14.20.

12.11.4 Effect on the river bed or sea bed. These possible effects will vary from site to site. In principal the unit floats and so generally has a limited effect on the river bed. If the PowerFrame is close to the river bed, or bottoms out at low tide then there could be some scouring effect. Due to the small scale of the device these will be very limited in any case and need to be evaluated on a case-by-case basis.

12.11.5 Potential for pollution. All appropriate legislation, such as the WEEE and RoHS Directives are adhered to. The materials selected have been chosen to minimise corrosion and the minimum amount of lubricant is used, and this is in a sealed enclosure. The use of an appropriate anti-fouling paint may be required in certain installation sites, but its use will be minimised.

12.11.6 Disposal at the end of its life. PowerFrame can be removed from its site leaving no damage to the previous infrastructure. PowerFrame is principally manufactured of aluminium and stainless steel which are readily recycled. There will be polymer material used in the floats and part of the selection criteria is that it is of a type that is widely recycled. An analysis will be carried out as part of the design process and an end of life procedure documented.

12.11.7 CO_2 payback is estimated at 2.3 months at a 3 knot tidal flow.

13) Surveys prior to new deployment.

13.1. Mechanical water flow devices have been used to date rather than an Acoustic Doppler Current Profiler due to the very high cost of such devices. The concept of PowerFrame is that it is a relatively low cost device, and the associated surveying, installation and licencing also need to be cost effective. Because of the small size of PowerFrame a pair of mechanical water flow meters can give a good representation of the average flow rate.

13.2 In a tidal area, the flow rate is measured at, or close to, the spring tide. This figure is used in the mathematical model to estimate the total energy that will be generated over a year, as described earlier in the report. Of course, the spring tides themselves vary on a cycle. See paragraphs 8.4 and 8.5.

13.3 It is impossible to be absolutely certain how much energy will be generated at any particular site prior to deployment. There are so many variables, which cannot be included in the mathematical model, that even with data from an ACDP over an extended period the output is not certain. Such variables include the shape of the sea or river bed, associated features such as river walls, bridge piers, large rocks or other features, the wider geography of the shape of the river, coats, islands, the catchment area for rainfall if the installation is in a river. In low cost installations the survey needs to be simple and give an acceptable accuracy.

13.4 This uncertainty has led to commercial difficulties with the very large tidal machines which cost 10s of million pounds because the "entry fee" is so high. The benefit of PowerFrame is that, following a simple survey, the machine itself can be tested in place, and if necessary, moved to another position in order to capture more energy.

13.5 As more PowerFrame machines are installed we will build up a history of our flow rate measurements and the associated annual energy generation which will help improve the accuracy of future predictions. This data will, in any event, be captured and available on the internet to customers and researchers.

13.6 For any given installation the duration of the survey depends on what local knowledge and data pre-exists. If no knowledge or data is available at all, then we would monitor the water flow rate at a depth of 1 m at a position representing the centre of the device for a period of two - three weeks to cover a spring – neap cycle. See paragraph 10.3.

13.7 The description above applies to small deployments of a single unit or a few machines. Clearly if a large array was being considered then a more thorough survey and study similar to that done by the MW machine developers would be required.

13.7.1 In addition, it would be practical to deploy a few PowerFrame to take measurements of the electrical power generated in various positions around the site, rather than just measuring the water flow rate. This takes away a lot of the variables which can influence the estimate of electricity to be generated from flow rate figures. The PowerFrame can operate in a standalone mode without grid connection dissipating the energy through heaters in order to be used in such a survey.

14) List of References

14.1. 10027-14 PowerTube Flyer.doc http://www.saundersenergy.co.uk/wp-content/uploads/2015/06/10112-3-PowerTube-HD-flyer-Arial.pdf

14.2. 10114-8 PowerFrame Flyer.doc http://www.saundersenergy.co.uk/wp-content/uploads/2015/06/10114-9-PowerFrame-flyer-Arial-compressed.pdf

14.3. Ofgem: Feed-in Tariff: Guidance for renewable installations (Version 5) 2013. https://www.ofgem.gov.uk/ofgem-publications/94301/fitgeneratorguidanceversion8march2015-pdf

14.4. Lyatkher. http://new-energetics.com/Main/Products.aspx A hydro unit is shown at the bottom of the page. Taking the power and flow data from the table, a C_p of 0.71 is calculated, which is above the Betz limit.

14.5. University of Aarhus paper. "Aarhus turbines May4_2009_1.pdf", and other sources. http://staff.iha.dk/sgt/Downloads/Turbines%20May4_2009_1.pdf

14.6. Alan Saunders. UK patent GB2487448. "A hydro-kinetic turbine assembly and a duct for such an assembly". 13th March 2013.

14.7. "PowerFrame Calculation of Power output Feb 2015 Sensitivity Analysis V2.pdf". See Appendix A.

14.8. "Data logging for PowerTube test rig rev2.pdf" includes specification sheets for components. See Appendix B.

14.9. PowerTube. "Calculation of Power output March 2012 Sensitivity Analysis.pdf". See Appendix C.

14.10. "Error analysis of dynamometer rev 2.pdf". See Appendix D

14.11. "Download date 23-27 Dec 14.xls". Relevant output shown in section 8 above.

14.12. "Download date 27-12-14 power.xls" (Noted for completeness).

14.13. ZERO, Norway: "Small-scale Water Current Turbines for River Applications.pdf" http://www.zero.no/publikasjoner/small-scale-water-current-turbines-for-river-applications.pdf

14.14. Delft University report on the development of the EcoWing profile, reports a C_p of 0.48 on p85. "Compare NACA0018 and DU 06-W-200 Claessens.pdf" http://www.lr.tudelft.nl/fileadmin/Faculteit/LR/Organisatie/Afdelingen_en_Leerstoelen/Afdeling_AEWE/Aerodynamics/Contributor_Area/Secretary/M._Sc._theses/doc/2006_1_17.pdf

14.15. "Model of power generated from a tidal curve.xls". See Appendix E.

14.16. European Marine Energy Centre document: "EMEC 2 Tidal Performance Standard.pdf" http://www.emec.org.uk/?wpfb_dl=31

14.17. "Bearing, Blade and Frame Design Jan 2015 – 4 knots rev 1.xls". A large spreadsheet available on request.

14.18. Not used.

14.19. EPRI "Evaluation of fish injury and mortality associated with hydrokinetic turbines.pdf". 2011. http://www.epri.com/abstracts/Pages/ProductAbstract.aspx?ProductId=000000000001024569

14.20. Ed Rowsell. Ecological Appraisal. See Appendix F.

14.21. Saunders Energy Limited, application for a Marine Licence. Follow this link to the MMO website https://marinelicensing.marinemanagement.org.uk/mmo/fox/live/MMO_PUBLIC_REGISTER/search?a and search for application MLA/2015/00177, or search for "Saunders Energy Limited". The entire application can be downloaded, but beware that it is a very large zip file.

14.22. Saunders Energy Limited: "Littlehampton Installation Method Statement V3a.pdf". Included in the MMO application.

14.23. Saunders Energy Limited: "Littlehampton Installation Risk Assessment V1a.pdf" Included in the MMO application.

Calculation of power output from PowerFrame

A Sensitivity Analysis

OVERVIEW

This document describes what can influence the amount of electrical power that is delivered to the grid from any fluid kinetic turbine, whether wind or water powered. In addition, specific features of PowerFrame are discussed. As with all such machines the major influence is the fluid flow velocity itself, although every feature contributing to the efficiency should be optimised.

Note that the Marketing Flyer, 10114-8, claims 2.3 kW_{ep} at 2.5 knots, calculated by this method reduces this to 2.1 kW_{ep}.

The product design specification power output target to the grid for PowerFrame is 1.9 kW_{ep} at 1.2 m/s.

SENSITIVITY ANALYSIS

It is convenient to split the analysis into two parts. First the power extracted from the fluid flow, then the inefficiencies in the means of delivering the electrical power to the grid.

Power delivered = power extracted from the fluid flow x efficiency of delivery.

Power extracted from the fluid flow.

The formula to calculate the power extracted from the fluid flow, whether a wind or water turbine is:

$$\text{Power} = \tfrac{1}{2} \cdot C_p \cdot \rho \cdot A \cdot v^3 \ \text{Watts}$$

C_p is the coefficient of performance, generally between 0.2 and 0.6, in this case measured at 0.32 during tests with the dynamometer turbine test rig. See note 1 below.

ρ is the fluid density, in this case 1025 kg/m^3 for sea water, fixed. It is 1000 kg/m^3 for fresh water.

A is the cross sectional area of the turbine, m^2, fixed for a given design. In this case 2.0 m x 4.0 m, or 8.0 m^2.

v is the free fluid flow rate, m/s, a variable.

Consider what can influence the variables.

1) C_p, the coefficient of performance. Generally a figure of 0.3 is used if the turbine characteristics are unknown. In this instance the wing has some history and has been tested by others. Our tests result in a figure of 0.32 but it is felt that this may be a little low. In addition the turbine blade struts for the production model will have a reduced resistance which will improve the performance further. Tests by others, from reports freely available on the internet show a range of 0.30 to 0.48 (Delft University). We use a figure of 0.34 in these calculations.
2) v, the free fluid flow rate. In this instance this is the river flow itself. As the value of v is cubed this is the most sensitive variable. The river flow rate has been measured using a calibrated flow meter. However, the flow has only been measured on the surface of the water, and it can be expected to reduce with increasing depth. As PowerFrame is 2.2 m tall there will be some effect here. It hasn't been possible to measure this yet. In addition this means that the water will be approaching the turbine with a velocity profile that is not orthogonal to its axis. This is likely to have a small effect, but it is unknown. It will actually be included in the measure of C_p from the practical tests.

For example if the water flow rate is 2.4 knots (1.2 m/s) then:

Power = ½ x 0.34 x 1025 x 8.0 x 1.2^3 = 2.4 kW_{mp}

	Minimum	Most likely individually	Maximum	Statistically likely	
Cp	0.30	0.34	0.40	0.35	
Density	1025	1025	1025	1025	kg/m^3
Area	8.0	8.0	8.0	8.0	m^2
River flow rate	1.15	1.20	1.25	1.20	m/s
Peak power	**1.9**	**2.4**	**3.2**	**2.5**	**kW_{mp}**

Note:

The minimum column contains the individual terms set to the minimum likely value, similarly the maximum column with maximum values. Neither of these combinations will occur in practice. Considering each term in turn for its most likely value gives the second column, again this is unlikely to happen as a whole. Using a root-mean-squared technique to establish an overall likely figure gives the statistically likely column.

Efficiency of delivery

Having extracted the power from the water it then has to be delivered to the grid via a generator, power electronics and inverter. Note that the turbine bearing losses are included in the value of C_p. All of these losses will be in the form of heat.

The formula to calculate the overall efficiency of delivery is to multiply the various efficiencies together.

In this instance, $\eta_d = \eta_s \cdot \eta_g \cdot \eta_i$

η_d is the overall efficiency of delivery.

η_s is the efficiency of the speed increaser. This is expected to be a two stage belt drive for the first unit. A single stage would be more efficient, but using a two stage model gives more flexibility to change the speed increasing ratio. This variable can be from about 0.85 to 0.98. ERIKS have quoted 0.97 minimum for each stage of our design. Thus the speed increaser will be 0.97 x 0.97 = 0.94 across its operating range.

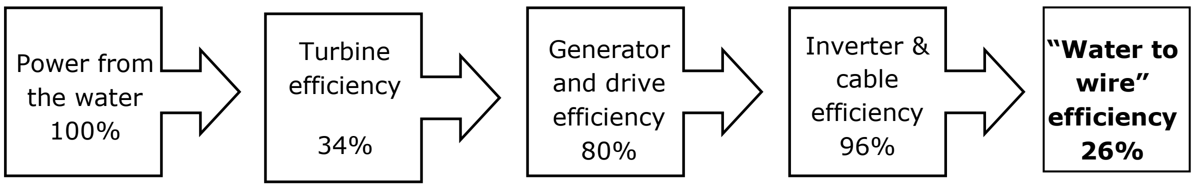
η_g is the efficiency of the generator, expected to be 0.85. This is for an Alxion manufactured permanent magnet generator. It can be from 0.75 to 0.90 depending on the operating point of a particular size and configuration of generator. The generator must be well matched to the turbine characteristics.

η_i is the efficiency of the inverter. This also depends on both the hardware and software. Some have a high efficiency but only at one operating point. This variable can be from 0.5 to 0.99. The inverter selected for use here will be 0.97 across its operating range.

Thus we have η_s = 0.94 x 0.85 x 0.97 = 0.78

Thus the overall expected power output at 1.2 m/s is 2.5 x 0.78 = 1.9 kW_{ep}

Definition:	kW_{ep}	Peak electrical power.
		The power out from the generator. This takes into account all of the system losses.
	kW_{mp}	Peak mechanical power.
		The power generated by the turbine alone.



Data logging for PowerTube: Turbine Test Rig

OVERVIEW.

PowerTube is a zero-head micro tidal turbine. See the marketing flyer for an overview. It is intended for use in shallow tidal areas, estuaries and rivers. Model tests and engineering analysis show that the output/cost equation is good and will give acceptable margins to everyone involved from component manufacturer to end customer.

A turbine test rig is being assembled for test in January and February 2014 in the River Arun and then Chichester Harbour. The test rig floats just below the surface of the water with the instrumentation on a bracket above the water.

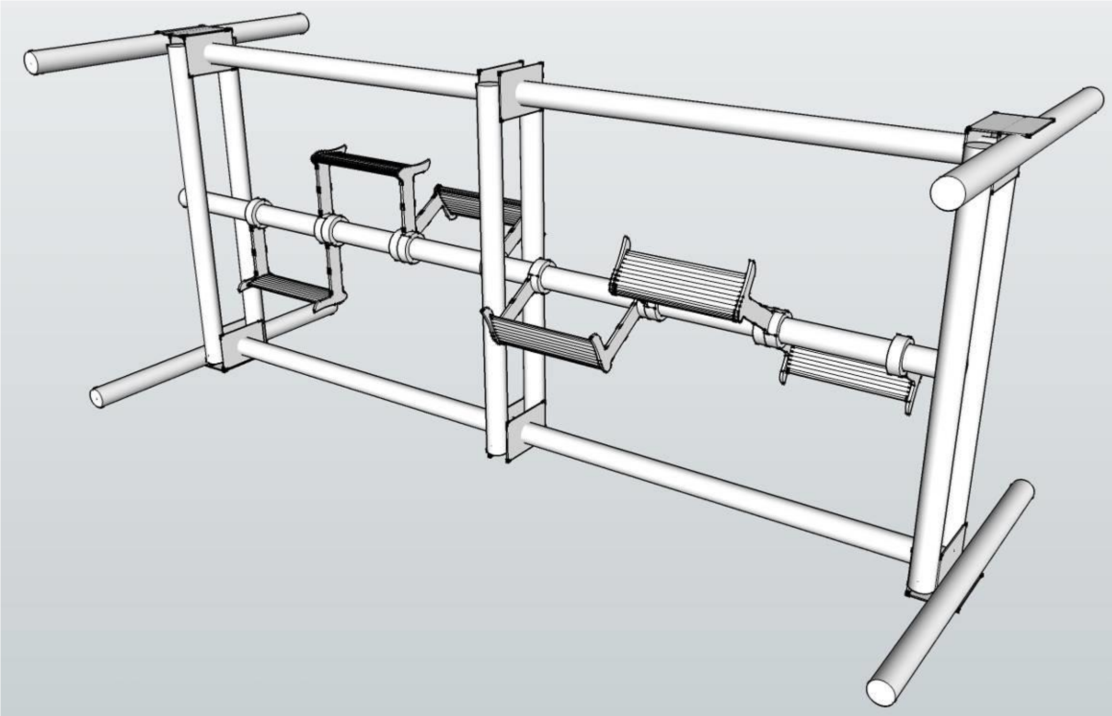
The purpose of the test is to demonstrate the relationship between water flow rate, turbine rotational speed, the load on a Prony brake and hence calculation of torque and power. This will allow confirmation of the customer pay-back for PowerTube.

INSTALLATION AND ENVIRONMENT.

The equipment will be mounted approximately 0.5 m above the sea water level on a bracket vertically above the Turbine Test Rig structure. It will be connected to the sensors by wires and to a monitoring PC or Android based system wirelessly. It will be subject to occasional splashes, and wind-borne salt water droplets. Depending on the IP rating of the components used it may be that the use of a waterproof box to contain all of the telemetry elements is appropriate. This may be supplied by Saunders Energy Limited, but would be manufactured by others.

The tests will require the telemetry to operate for about 12 hours, then the test rig will be recovered to land for mechanical checks, cleaning and moved to the next test position for another day. The system will be required to be battery powered and this should have a specified life of 18 - 24 hours before re-charging. Temperatures could be -5°C to +30°C.

The drawing below is typical and not a detailed representation of the test rig. Each lower corner carries a castor and each upper corner carries a buoy for flotation.



MEASUREMENTS.

Water flow rate.

This is currently measured using a NASA Marine Instruments Limited Target Speed and Distance Log as described on this link. [Products: NASA Marine Instruments]

A small impeller is rotated by the water flow. The impeller has two magnets fitted, 180° out of phase, and so gives 2 pulses per rev. The (battery powered) display is calibrated to display knots of water speed. I plan to cut into the lead between the impeller and the display and take a parallel signal cable to the data logger. The voltage for the pulse is provided by the NASA display internal batteries.

The calibration of the data logger engineering unit output can be altered until it gives the same reading as the NASA display. This can be done in the workshop initially using the velocity of air from a fan to rotate the impeller and then re-checked next time out in the water.

The water flow can vary time-wise second to second, by say, +/- 30% at low flow rates due to eddies and turbulence in the flow. The NASA log has an in-built averaging algorithm. We will need to experiment with an appropriate duration over which to average, perhaps a period from (no averaging) up to 30 s maximum. I would expect the period to be about 5 s. In other words, count the number of pulses during 5 s, apply the calibration factor and display the water speed in knots against time. We should also display the speed in m/s against time.

In the areas where PowerTube will be installed, at higher flow rates the water is more stable with less eddies and turbulence.

The impeller is very lightweight and so responds to changes in water velocity very rapidly, which gives rise to the need for an averaging algorithm.

Turbine rotational speed.

Four equispaced magnets are to be bonded to the shaft, and a reed switch with a suitable characteristic, i.e. operates fast enough, fixed on an adjustable bracket nearby. Thus 4 pulses per rev will be triggered. The voltage for the pulse needs to come from the data logger. The engineering unit output should be rpm, so the scaling factor is /4 and *60, or 15 in total?

The turbine is 3.5 m long and weighs about 50 kg so has sufficient inertia that it will not respond very much to eddies and turbulence in the water. However, the nature of the mechanism chosen for this turbine results in 6 large and 6 small torque impacts ("thumps") per rev. I want to investigate this effect at some point, but it is not essential for this set of tests. This will require looking at the time between impulses and displaying how consistent this is.

For the immediate tests I need to measure and display the average rotational speed and display this in rpm against time.

Load on the Prony brake.

An adjustable friction brake is to be provided which allows a load to be put on to the turbine. A load cell will provide an output of 2 mV/V applied for FSD. I would expect to use a 500 kg load cell. The power supply should be from the data logger, and needs to be a stable voltage. The load cell can use up to 10 V. Assuming a 5 V supply it will output 10 mV/500 N, we need to measure a minimum of 1 N steps or 0.02 mV. Preferably we can measure to 0.1N, or 0.002 mV. (AD-08 input resolution is 0.01 mV, giving 0.5 N step. This is acceptable).

The load cell I am planning to use is shown at the end of this document.

It is rated to IP68 and will be mounted underwater at a radius of 1/3 m, (0.3333 m).

This load, Newtons, multiplied by the lever arm (radius) of the brake, will indicate the torque being generated, Nm. The power, Watts, generated is calculated by Torque, Nm multiplied by rotational speed, rad/s. Display Brake load, Torque and Power against time.

	TURBINE TEST RIG				
ID	*Parameter*	*Display, engineering units*	*Input to data logger*	*How measured*	*Comment*
1	Rotational speed of shaft	0 - 300 rpm, XXX.X	Switching, 4 pulses per rev	Reed switch, 4 magnets around shaft	
2	Water flow rate 3 m in front of the unit	0 - 4 m/s, display in knots too. X.X and X.X	Switching, 2 pulses per rev	NASA impeller signal	How do we calibrate? Allow adjustment on site?
3	Force applied to brake	0 - 300 kg, XXX	0-5V? Proportional to force applied	**Load cell, see spec.**	
4	Torque applied to shaft	0 - 1300 Nm, X,XXX	-	Force * 9.81 * 0.3333	Allow the 0.3333 m to be an input in case the hardware varies from this.
5	Power at shaft	0 - 40 kW, XX.XX	-	Torque * (rotational speed, rad/s)	
6	Tip speed ratio	0 - 5, X.X	-	Linear speed of turbine blade/water speed	
7	Hydraulic pressure	0 - 200 bar, XXX	0 - 10 V from transducer	See spec sheet.	
8	Control of hydraulic pressure	"INCREASE" and "DECREASE" controls on display	OUTPUT 0 - 10 V to proportional valve	OUTPUT	
9	System voltage	12V, XX.X	Nominal 12V	At battery?	
10	Switch on/off hydraulic pump	"PUMP ON/OFF" displayed	OUTPUT to relay	Relay switches pump to battery	Record time
11	Averaging time of rotational speed of shaft	seconds, XX		Start with 5 s, able to vary from 0 - 60 s	Each parameter with an averaging time to record the raw data
12	Averaging time of water flow rate	seconds, XX		Start with 10 s, able to vary from 0 - 60 s	Each parameter with an averaging time to record the raw data
13	Averaging time of force	seconds, XX		Start with 5 s, able to vary from 0 - 60 s	Each parameter with an averaging time to record the raw data

DESCRIPTION OF TESTS.

The frame will be launched on castors on a slipway and towed by boat to the test site. At the test site the frame will be securely tied to piles or a pontoon. Operators will be either on the pontoon or in a boat within say 10 m of the test rig.

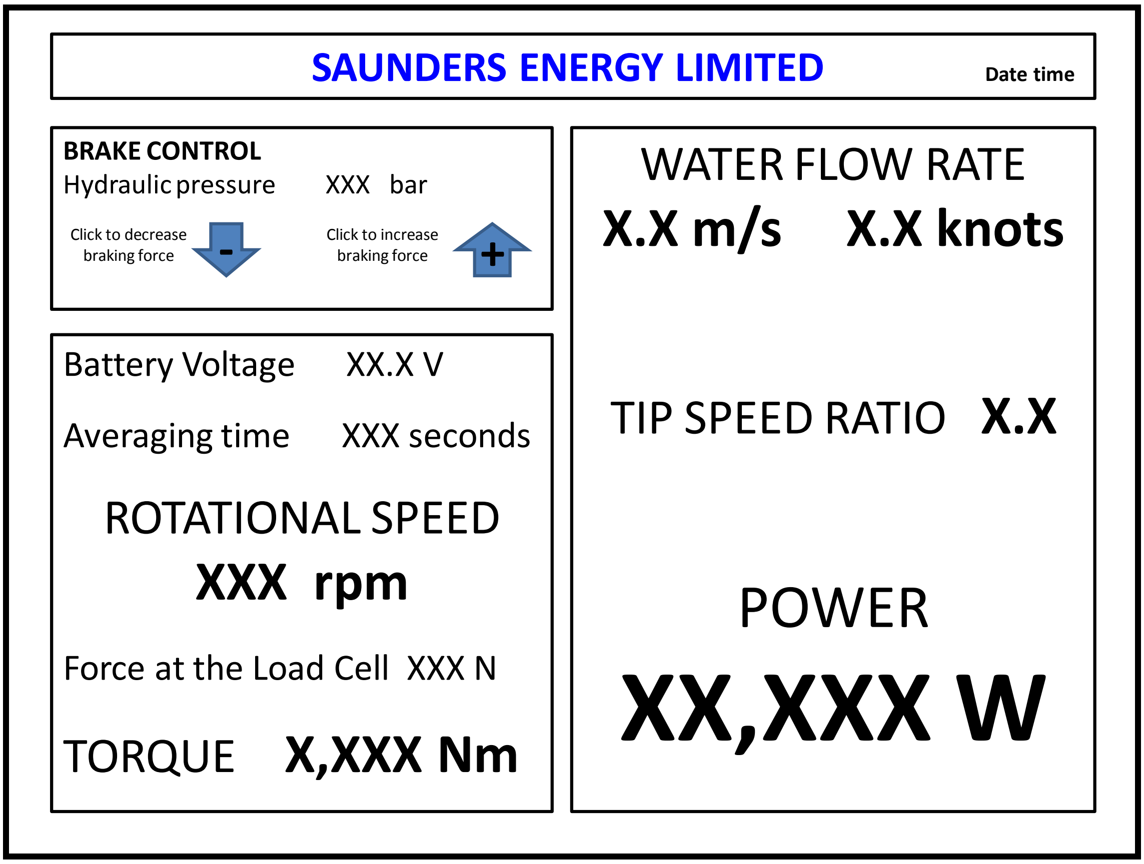
The frame will be launched at high tide when there is little water flow and as the flow rate increases to a maximum about 4 - 5 tests will be done, depending on the time available. The test will constitute starting with no brake to get the zero torque, no-load speed. Then gradually applying the brake and measuring water speed, rotational speed and torque and various loads until the turbine is stalled. Then the brake is released and another set of results taken.

The first set of tests is in the River Arun at Littlehampton with the test rig against an easily accessible pontoon. Here the water will go from 0 knots to about 2.5 knots in about 3 – 4 hours. The rate of change is slow and it will allow time for de-bugging the tests.

The test rig will be removed from the river and modifications made if necessary. About two weeks later tests will be carried out in Chichester Harbour. This time the test rig will be supported against a pile in the middle of the harbour entrance which is only accessible by boat. This time the flow rate will reach close to 7 knots, the rate of change is quicker as these tests will occur over the same time frame as those in Littlehampton.

SUGESTED LAYOUT OF DISPLAY

The following screen is not a request and is not aesthetically very good. However, it contain the information that I think should be displayed and the relative importance of each item. Please discuss!



Issue:	Date:	Created/Amended by and details:
1	04-12-13	AS: draft for discussion
2	31-01-14	AS: table of parameters added. Spec sheet for load cell and hydraulic equipment added. Suggested layout of output screen. Drawing of brake layout 10129rev5 included.

Shearbeam Load Cell, Model 3510

- High accuracy and long term stability
- Output signal rationalised (2 mV/V ± 0.1%)
- 'T' end option current matched as standard
- Available in capacity ranges from 300kg to 5000kg
- Ideal for harsh environments & Industrial applications
- Stainless steel construction hermetically sealed IP68
- Optional ATEX approval available
- 6-wire sense technique with double shielded cable
- Optional live end hole for low profile loading foot

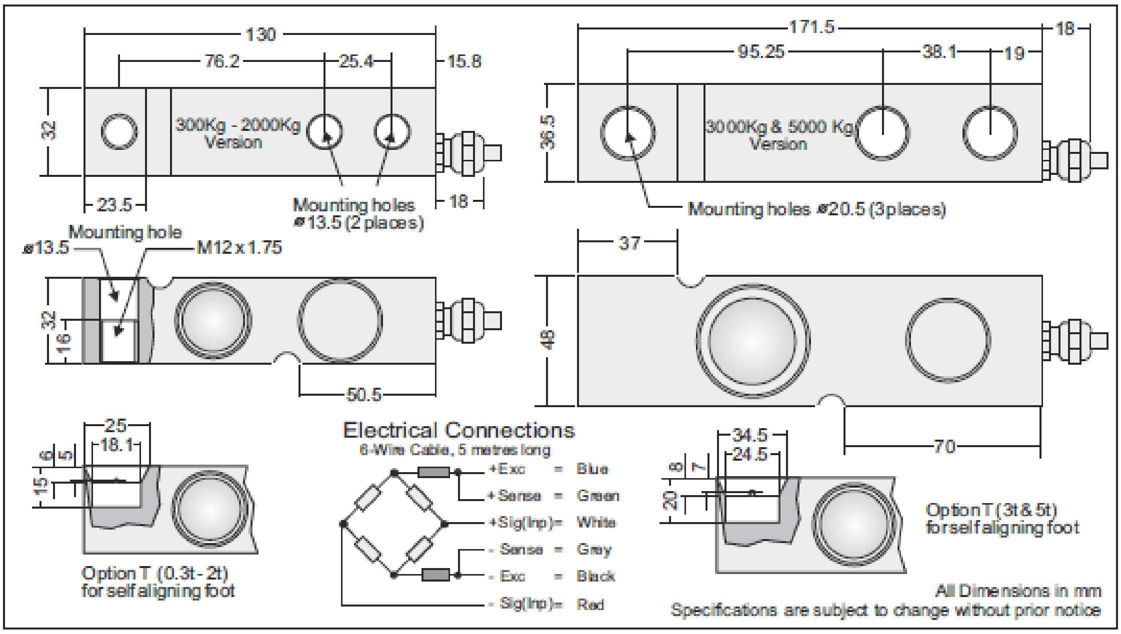
Technical Data

Model 3510

GRADE		C1	C3	C6
Number of Load Cell Intervals	n (max)	1000	3000	6000
Minimum Utilisation	% Rated Cap.	30	25	40
Minimum Verification Interval	Vmin=Emax/.	3333	12000	15000
Total Error	% Appl. Load	0.050	0.020	0.010
Zero Return after 30 mins	% Appl. Load	0.050	0.017	0.008
Temperature Effect on : Span	%Appl. Ld./10K	0.040	0.010	0.006
Zero	%ORL/10K	0.035	0.023	0.024
Output at Rated Load (ORL)	mV/V	2.00 (UR matched 2.02)		
Output at Rated Load Tolerance	%	± 0.1		
Input Impedance	Ohm	380 ± 10		
Output Impedance	Ohm	350 ± 3		
Recommended Supply Voltage	V	10		
Compensated Temp. Range	°C	-10 to +40		
Operating Temperature Range	°C	-30 to +70		
Deflection	mm	< 0.4		
Safe Overload	% Rated Cap.	150		
Maximum Overload	% Rated Cap.	200		
Ultimate Overload	% Rated Cap.	300		
Cable Length	m	5		
Construction		Stainless Steel		
Environmental Protection		IP68		
Rated Capacities (Emax)	Kg	300, 500, 1000,1200, 2000, 3000, 5000		

NMI - Certificate TC2272, OIML-R60. C6 grade only available for capacities 300-1200kg.

Dimensions



DS3510-4, 09/10

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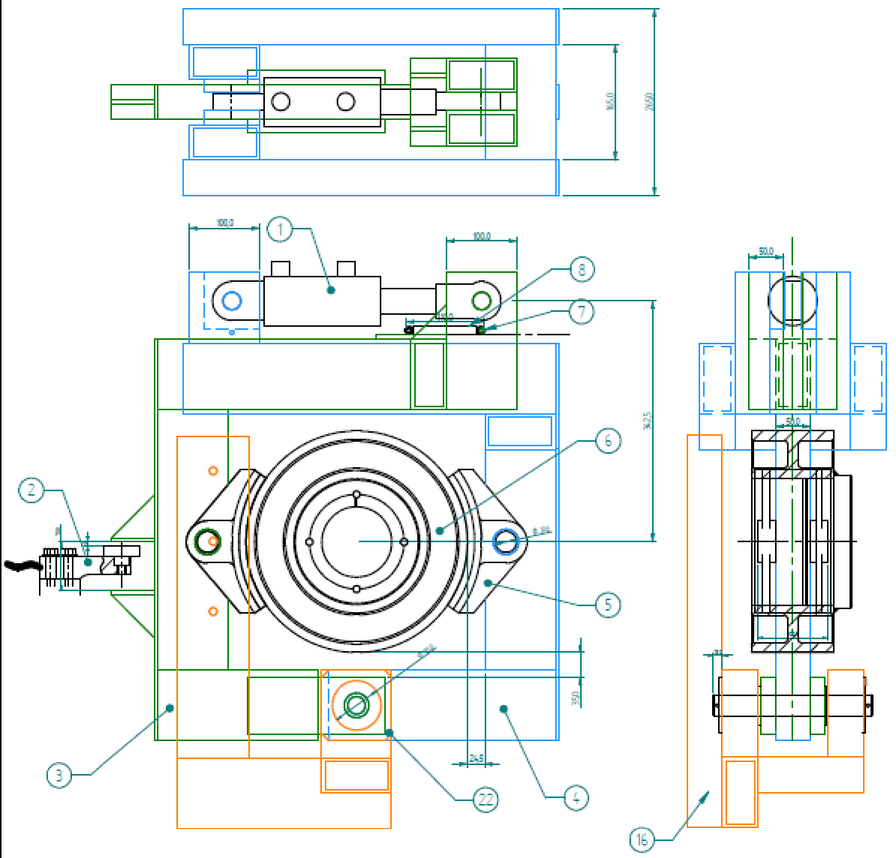
REVISION HISTORY				
REV	ECR No	DESCRIPTION	DATE	APPROVED
1		First Revision	17-01-14	AS
2		Shoes changed to pivoting type, Frame changed to solid section, other updates	21-01-14	AS
3		Drum dia reduced to 316, use off-the-shelf shoes. Frame tubular.	25-01-14	AS
4		More detail added. Cylinder changed and both calipers to suit.	28-01-14	AS
5		Clash of calipers corrected. Brake support bracket modified	29-01-14	AS



N.B. ITEMS 9 TO 15 AND 17 TO 20 NOT SHOWN

Parts List			
Part No.	Drawing Number	Description	No. off
22	10136	Retaining plate 100 X 100 X 6	2
21	AM304050	Bush PB bore 30 X OD 40 X 50 long Brake shoe support	2
20	AM253550	Bush PB bore 25 X OD 35 X 50 long Lower pivot & rod end	3
19	AM253230	Bush PB bore 25 X OD 32 X 30 long Cylinder end	2
18	AM253220	Bush PB bore 25 X OD 32 X 20 long Lower pivot	2
17	AM404650	Bush PB bore 40 X OD 46 X 50 long Lower pivot	2
16	10135	Brake support bracket (orange) 5.3 kg	1
15		Dia 4 x 45 A4 split pin	10
14		M24 form B washers A4 (2.5 thick)	6
13		M30 form B washers A4 (2.5 thick)	4
12	10139	Lower pivot pin dia 25 X 224 316SS	1
11	10138	Cylinder pins dia 25 x 146 and 185 316SS	2
10	10137	Brake shoe pin dia 30 x 120 316SS	2
9		Spring retaining strap (not shown)	1
8	RS121-321	Extension Spring	1
7		Spring retaining stud, M6 allthread X 150 and 190	2
6	10133	Brake drum with taper lock bush 100 bore	1
5	(10127)	Brake shoe assembly, aluminium, FTL161	2
4	10131	Trailing brake caliper (blue) 11.5 kg	1
3	10130	Leading brake caliper (green) 9.5 kg	1
2		Loadcell IP68 500 kg	1
1		Hydraulic cylinder 70 bore, 200 stroke NFR4400200	1

	NAME	DATE
DRAWN BY	Owner	29/01/14
CHECKED		

FILE NAME: 10129rev5 Brake assembly.dft

enquiries@saundersenergy.co.uk

UNLESS OTHERWISE SPECIFIED
Dimensions in millimetres
Linear dimensions: X ±0.5 X.X ±0.2 X.XX ±0.1
Angular dimensions: X ±1.0 X.X ±0.2

3rd ANGLE PROJECTION

Saunders Energy Limited

TITLE: Brake assembly

SIZE: A3 | DWG NO: 10129 | REV: 5

MATERIAL:

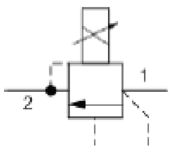
SCALE: 1 : 5 | WEIGHT: | SHEET 1 OF 1

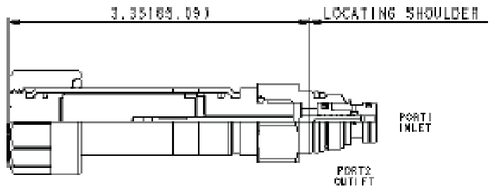
REMOVE ALL BURRS AND SHARP EDGES

snhy.com/rbap-xan

MODEL
RBAP-XAN

Electro-proportional relief valve - pilot capacity
CAPACITY: .25 gpm | **CAVITY:** T-8A





CONFIGURATION:

X	Control	No Manual Override
A	Adjustment Range	300 - 3000 psi (20 - 210 bar)
N	Seal Material	Buna-N

This 2-port, pilot-stage, direct-acting relief cartridge is an electro-proportionally controlled, pressure regulating valve. The proportional control allows for infinite, step-less adjustability within the selected pressure range. When the pressure at port 1 (inlet) is sufficient to overcome the solenoid forces, as determined by the analog input signal, the poppet lifts and allows flow from port 1 to port 2 (outlet). This pilot control cartridge utilizes the T-8A cavity so it can be used in conjunction with Sun's main stage, pressure control elements.

RELATED ACCESSORIES:

773-812
773-814
773-824
773-828
991-070
991-238

NOTES:

Please verify cartridge clearance when choosing a Sun manifold. Different valve controls and coils require different clearances.

TECHNICAL DATA:

Cavity	T-8A
Series	P
Capacity	.25 gpm
Hysteresis (with dither)	<4%
Hysteresis with DC input	<8%
Linearity (with dither)	<2%
Repeatibility (with dither)	<2%
Recommended dither frequency	140 Hz
Maximum Operating Pressure	5000 psi
Maximum Valve Leakage at Reseat	1.5 in³/min.
Reseat	>85% of setting
Solenoid Tube Diameter	.75 in.
Valve Hex Size	7/8 in.
Valve Installation Torque	20 - 25 lbf ft
Model Weight (with coil)	1.00 lb
Seal kit - Cartridge	Buna: 990-208-007
Seal kit - Cartridge	Viton: 990-208-006
Seal kit - Coil	Viton: 990-770-006

The above proportional valve is physically connected to the coil shown on the next page.

sun hydraulics®

snhy.com/790-2b12v-us

MODEL
790-2B12V-US

12 VDC coil with embedded proportional amplifier, voltage command

The Embedded Electronics Amplifier is a compact, low profile coil/controller combination for use with proportional solenoid valves. The Amplifier provides current to the coil in proportion to an input signal. Bright LED indicators on the unit provide an overview of the operating status. Setup is accomplished through Sun's Amplifier Set Up Software or the Hand Held Programmer (HHP). There is no cover to remove and no tiny pots to set. Once configured, the settings are stored in permanent memory within the unit.

USED WITH:

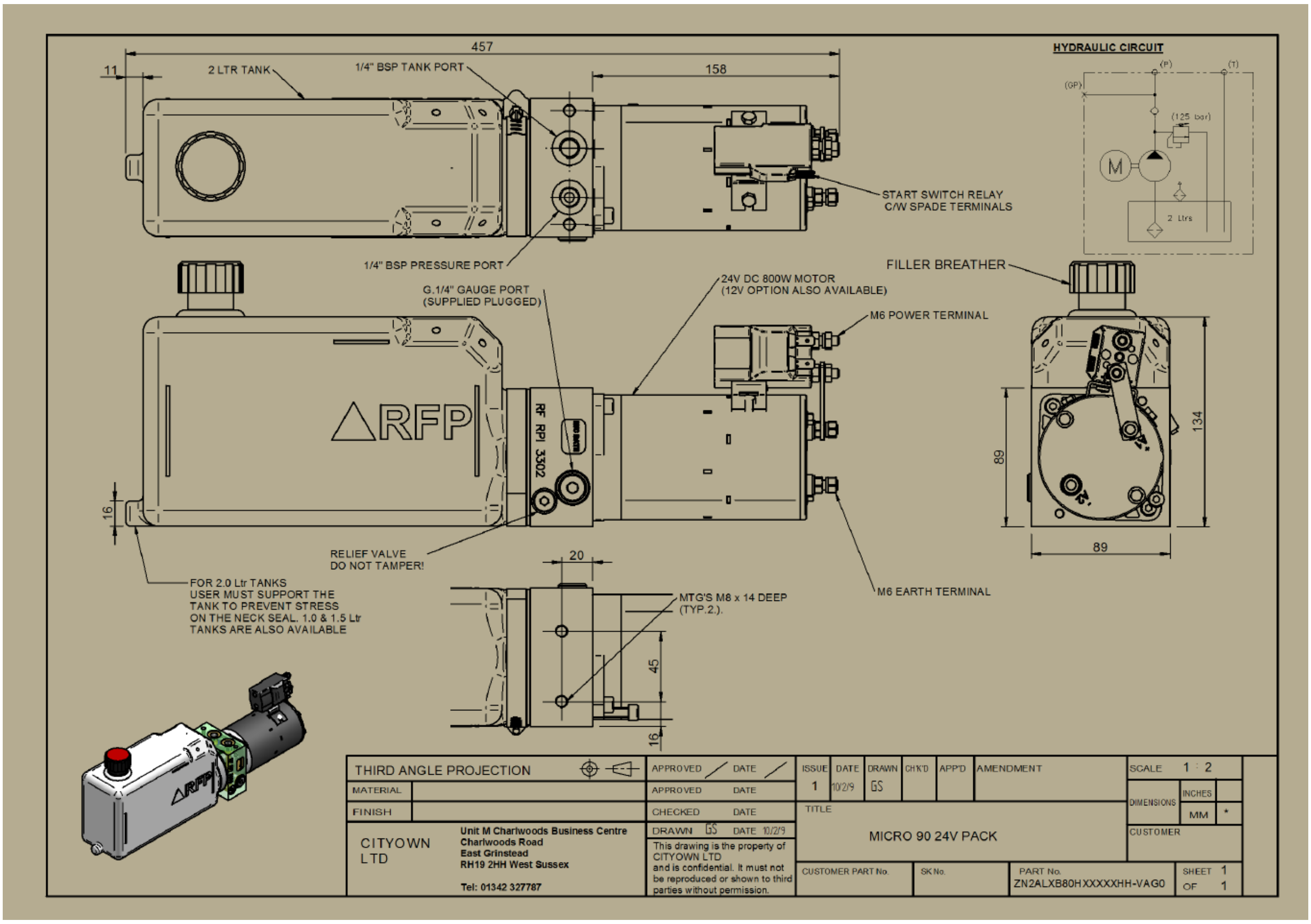
FMDA FMDB FPCC FPCH FPHK
PRDL PRDM PRDN PRDP PSDL
PSDP RBAN RBAP

NOTES:

A source type input is required. A sinking type analog input will damage the amplifier.

TECHNICAL DATA:

Output Current	1200 mA
Supply Current	I(sol) + 20mA
Dither Settings	Off, 80-300 Hz, in 20 Hz increments
Analog Input Range	0-10V
Analog Input Impedance	13 Kilo-ohms
Ramp Time	0-120.0 s, 0.5 s increments
Card Function	Ground Option
Voltage/Frequency	12 VDC
Supply Voltage	Equals coil voltage within +/-10%
Operating Temperature Range	-4 - 158 °F
Connector	ISO/DIN 43650A, Form A
Connector Environment Rating	IP65



The 12V version, 500W is to be supplied for this project.

The **hydraulic pressure sensor** is a Wika unit part number 12719332. Data sheet on the RS website at:

http://docs-europe.electrocomponents.com/webdocs/0f16/0900766b80f165aa.pdf

Calculation of power output from PowerTube

A Sensitivity Analysis

(This document replaces the issue dated October 2011. PowerTube now has larger dimensions generating more power).

OVERVIEW.

This document describes what can influence the amount of electrical power that is delivered to the grid from any fluid kinetic turbine, whether wind or water powered. In addition specific features of PowerTube are discussed. As with all such machines the major influence is the fluid flow velocity itself, although every feature contributing to the efficiency should be optimised.

In the River Arun at Littlehampton, opposite the Black Shed, the overall expected power delivered to the grid is between 3.8 and 4.4 kWp

SENSITIVITY ANALYSIS

It is convenient to split the analysis into two parts. First the power extracted from the fluid flow, then the inefficiencies in the means of delivering the electrical power to the grid.

Power delivered = efficiency of delivery x power extracted from the fluid flow

Power extracted from the fluid flow.

The formula to calculate the power extracted from the fluid flow, whether a wind or water turbine is:

$$\text{Power} = \tfrac{1}{2} \cdot C_p \cdot \rho \cdot A \cdot (v \cdot a_d)^3 \ \text{Watts}$$

C_p is the coefficient of performance, generally between 0.2 and 0.6.

ρ is the fluid density, in this case 1050 kg/m^3 for sea water, fixed. It is 1000 kg/m^3 for fresh water

A is the cross sectional area of the turbine, m^2, fixed for a given design. In this case 0.83 m x 3.2 m, or 2.6 m^2.

v is the free fluid flow rate, m/s, variable.

a_d is the relative acceleration of the fluid flow due to the effect of the duct. This has a value of 1.0 if there is no duct and no reduction due to local conditions or greater than 1.0 if there is acceleration.

Consider what can influence the variables.

1) C_p, the coefficient of performance. Generally, a figure of 0.3 is used if the turbine characteristics are unknown. In this instance a Darrieus turbine is used and the configuration is similar to that used by Lyatkher of New Energetics, USA. His configuration is more efficient than a standard Darrieus turbine layout. According to his documentation C_p has the value of 0.7 which he claims is derived from test work. Documentation is available. The theoretical maximum figure is generally regarded as 0.59. I have taken a figure of 0.5 for my calculations.
2) v, the free fluid flow rate. In this instance this is the river flow itself. As the value of v is cubed this is the most sensitive variable. The river flow rate has been measured using a calibrated flow meter. However, the flow has only been measured on the surface of the water, and it can be expected to reduce with increasing depth. As PowerTube is 2.7 m tall there will be some effect here. It hasn't been possible to measure this yet. In addition this means that the water will be approaching the turbine with a velocity profile that is not orthogonal to its axis. This is likely to have small effect, but it is unknown.
3) a_d, the relative acceleration of the fluid flow. The duct has been designed to optimise the acceleration of the water onto the turbine in order to take advantage of the cube law. The PowerTube duct is unique and has features that are the subject of a patent application. There is much literature and many claims about the acceleration due to a duct in this situation. Generally, "properly" tested ducts give an acceleration from 1.2 to 1.4. Will Batten at Southampton University reckons that a good duct should achieve 1.4. My tests to date have repeatedly demonstrated 1.8 for the duct without the turbine fitted. Fitting the turbine will reduce this figure. Further calculations and tests imply a reduction to 1.54 is appropriate.

It is felt that using $C_p = 0.5$ and an acceleration of v of 1.54 will give conservative figures without them being unnecessarily pessimistic.

For example if the water flow rate is 2.4 knots (1.2 m/s) then:

Power = ½ x 0.5 x 1050 x 2.6 x $(1.2 \times 1.54)^3$ = 4.4 kWp

If the water flow is increased to 2.8 knots (1.4 m/s) then:

Power = ½ x 0.5 x 1050 x 2.6 x $(1.4 \times 1.54)^3$ = 5.8 kWp

	Minimum	Likely individually	Maximum	Statistically likely	
Cp	0.3	0.5	0.7	0.53	
Density	1050	1050	1050	1050	kg/m3
Area	2.65	2.65	2.65	2.65	m2
River flow rate	1.0	1.2	1.4	1.21	m/s
Acceleration	1.4	1.54	1.8	1.59	
Peak power	**1.1**	**4.4**	**15.6**	**5.2**	**kWp**

Note for mathematicians! The minimum column contains the individual terms set to the minimum likely value, similarly the maximum column with maximum values. Neither of these will occur in practice. Considering each term in turn for its most likely value gives the second column, again this is unlikely to happen as a whole. Using a root-mean-squared technique to establish an overall likely figure gives the statistically likely column.

Efficiency of delivery

Having extracted the power from the water it then has to be delivered to the grid via a generator, power electronics and inverter. Note that bearing losses are included in the value of C_p. All of these losses will be in the form of heat.

The formula to calculate the overall efficiency of delivery is to multiply the various efficiencies together.

In this instance, $\eta_s = \eta_g \cdot \eta_e \cdot \eta_i$

η_s is the overall system efficiency.

η_g is the efficiency of the generator, expected to be 0.87, it can be from 0.60 to 0.95 depending on type, construction, quality of materials and size. This can vary widely according to the operating point unless the generator is well matched to the turbine characteristics. The generator proposed here is a "state of the art" device which could be improved further by some customisation to the characteristics of the PowerTube turbine. For the generator selected here, being cautious, this could be from 0.77 to 0.90.

η_e is the efficiency of the power electronics or inverter interface. This depends on both the hardware and any associated software. Some have a high efficiency but only at one operating point. This variable can be from 0.85 to 0.999. The interface selected for use here will be 0.994 across its operating range.

η_i is the efficiency of the inverter. This also depends on both the hardware and software. Some have a high efficiency but only at one operating point. This variable can be from 0.5 to 0.99. The inverter selected for use here will be 0.97 across its operating range.

Thus we have $\eta_s = 0.87 \times 0.994 \times 0.97 = 0.84$

or $\eta_s = 0.77 \times 0.994 \times 0.97 = 0.74$

Thus the overall expected power output is 5.2 x 0.84 = 4.4 kWp (or 3.8 kWp)

The range of power output expected considering the variables described above is between 3.8 and 4.4 kWp.

TECHNICAL REPORT

ERROR ANALYSIS OF TURBINE TEST RIG DYNAMOMETER

Report by: Alan Saunders

SUMMARY

This report examines the likely errors inherent in the dynamometer used to measure the power of the turbine test rig. These measurements, along with an estimated efficiency for a generator, have been used to estimate the power that will be generated by the complete product. The power generated implies the income for the owner, and hence allows calculation of payback.

The dynamometer is accurate to within + 1.20 % and – 1.00 % of the reported figure. This would be to a normal distribution of errors so statistically there is a 95 % chance* that it is

+0.80 % and – 0.67 % of the reported figure.

Bear in mind that this is the accuracy of the measurement of the applied force. It depends on the correct – the maximum for any given water flow rate without stalling - braking force being applied.

* See the Appendix

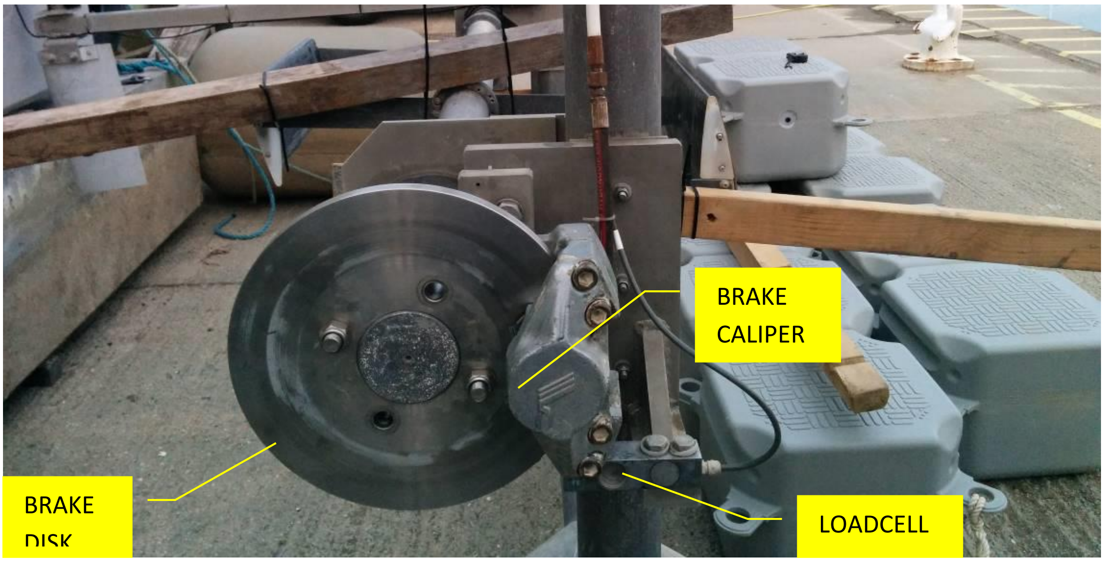
Discussion

The turbine test rig consists of the turbine in the proposed configuration including production design bearings. The power generated is measured using a dynamometer.

Power being torque x rotational speed. With torque being load x the radius it is applied at.

The dynamometer allows these measurements to be made. The torque is measured using a disk brake whose caliper rests on a calibrated load cell. The rotational speed is measured with magnets fixed around the shaft triggering a stationary magnetic switch.

The signal from the load cell and from the magnetic switch are monitored and recorded by the iDAQ datalogger.



Measuring the torque

The following chart indicates what aspects of this measurement need to be considered when evaluating the accuracy.

Turbine in bearings being measured for torque, Nm

1) Brake disk radius, m

2) Friction on brake caliper slide, -N

3) Force from caliper on load cell, N

4) Accuracy of the iDAQ data logger.

1) The brake disk radius is measured to +/- 0.5 mm using a vernier caliper. It is 140 mm, thus a potential error of +/- 0.357 %. Note that this radius is from the centre of the shaft to the centre of the pair of pistons of the brake caliper.
2) The friction on the brake caliper slide is unknown. It is likely to be less when submerged and being subject to constant movement. A measurement can be taken of it dry and stationary, and if this is a small number then use that. If it is a number that influences the result then further investigation will be needed.
3) The load cell is calibrated as shown below.

MODEL 3510 500KG

LOAD CELL ACCEPTANCE TEST

STAINLESS STEEL

SERIAL NUMBER 28164680
ACCURACY CLASS G-C3/25

OUTPUT AT RATED CAP	2.0148 MV/V		
ZERO BALANCE	0.0030 MV/V	TOTAL ERROR	0.0156 % R.O.
30 MIN. ZERO RETURN	0.0000 % Load		
		INSULATION RESIST	> 2000 M Ohm
TEMP EFFC.ON ZERO	-0.0004 %R.O/DEG C°	INPUT IMPEDANCE	380 ±10 Ohm
TEMP EFFC.ON SPAN	0.0011 %LOAD/DEG.C°	OUTPUT IMPEDANCE	355 ± 5 Ohm

COLOR CODE

BLUE	.....+ INPUT	BLACK	.....- INPUT
GREEN	.....+ SENSE	GRAY	.....- SENSE
WHITE	.....+ OUTPUT	RED	.....- OUTPUT

Pb RoHS

QA APPROVED

TEDEA - HUNTLEIGH
11/11/2013
TC-001

a) The total error is 0.0156 % of the applied load (certificate above says of the RO, or rated output. See the data sheet and description of the load cell.) All of the other errors, described below for completeness, are incorporated in this figure.

b) The temperature effect on the zero point is -0.0004 % of 500 kg, or -0.2 kg.

c) The temperature effect on the span is 0.0011 % of the load, kg, which is effectively + 0.0011 % of the reading.

4) The iDAQ datalogger is shown below and described in the manual, details below.

a. The iDAQ software uses the nominal figure of 2.0000 mV/V but, from above, the actual load cell generates 2.0148 mV/V. Thus the reading will be +0.74 %

b. +/- 0.10 % on Voltage measurement, which is directly proportional to the reported torque.

The **combined accuracy** of measuring the applied torque is

Feature	+ tolerance %	-tolerance %
Brake disk radius	0.3570	-0.3570
Brake caliper friction	???	???
Load cell	0.0078	-0.0078
iDAQ data logger	0.8400	-0.6400
Total error on torque measurement	1.2048	-1.0048

Measuring the rotational speed

Similarly the following chart indicates what aspects of this measurement need to be considered when evaluating the accuracy. The sensor works by four magnets attached around the shaft which cause a single magnetic switch to close and open as they go past. The iDAQ data logger counts the pulses. The system is digital and operating at a low frequency.

Turbine in bearings being measured for rpm

1) Number of magnets
2) Quality of magnetic switch
3) Accuracy of the iDAQ data logger.

1) The number of magnets is 4 and cannot change.
2) The magnetic switch could potentially “bounce” and cause a double measurement. It is rated as completing an open-and-close cycle in 0.6 msec. This is 1667 Hz. The turbine will run at, say 200 rpm maximum with 4 switches per revolution. This is 13 Hz, so bouncing won’t happen.
3) The iDAQ can count accurately up to 1000 Hz and so won’t introduce an error.

The **combined accuracy** of measuring the rotational speed is

Feature	+ tolerance %	-tolerance %
Number of magnets, 4	0.0000	-0.0000
Quality of magnetic switch	0.0000	-0.0000
iDAQ data logger	0.0000	-0.0000
Total error on rotational speed measurement	0.0000	-0.0000

Calculation of accuracy

Clearly the accuracy is the same as the accuracy of the torque measurement which is

+1.20 % to – 1.00 % of the reading.

Conclusion

Given the application of the correct braking force the power measurement is very accurate being better than a 1 % error.

References to other documents

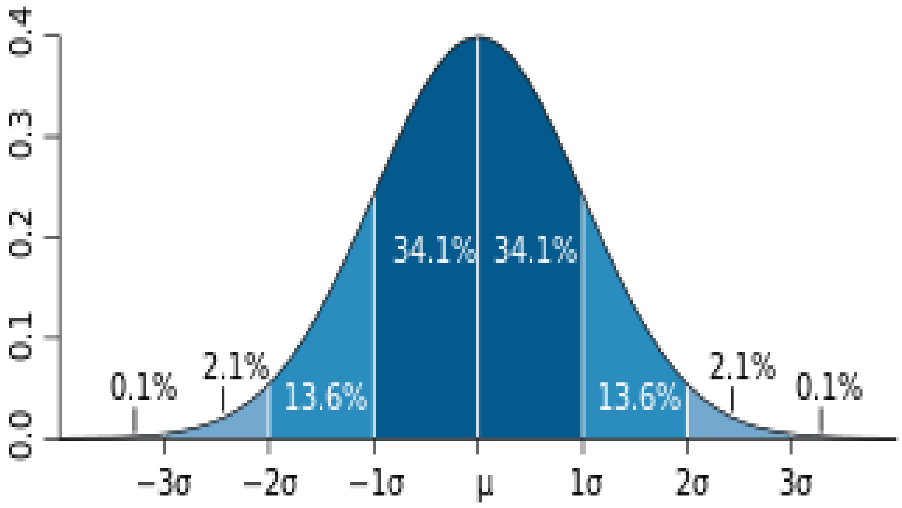
1) iDAQ_Manual.pdf
2) PowerTubeTestRig - Ver 2.pdf
3) Data Logging for PowerTube test rig rev 2.pdf (includes load cell spec).

DOCUMENT CONTROL

Issue	*Date:*	*Created/Amended by and details:*
1	16-10-2014	AS: initial draft.
2	18-10-2014	Explanatory notes added.
3		
4		

Appendix

Assuming a normal distribution of the errors then 95% of the error will be +/-2 standard deviations of the distribution.



Dark blue is less than one standard deviation away from the mean. For the normal distribution, this accounts for 68.2% of the set, while two standard deviations from the mean (medium and dark blue) account for 95.4%, and three standard deviations (light, medium, and dark blue) account for 99.7%.

+/- 3σ is 2.200 %, so +/- 2σ is 1.46 %.

APPENDIX E

Model of power generated from a tidal curve.xls

Peak tidal flow rate	4.0	knots
Inlet area	2.25	m2
rea of turbine housing	0.36	m2
Area of turbine	0.31	m2
Generator size	100.0	kW

Notes
1) The power cube law flattens available power at low water velocities.

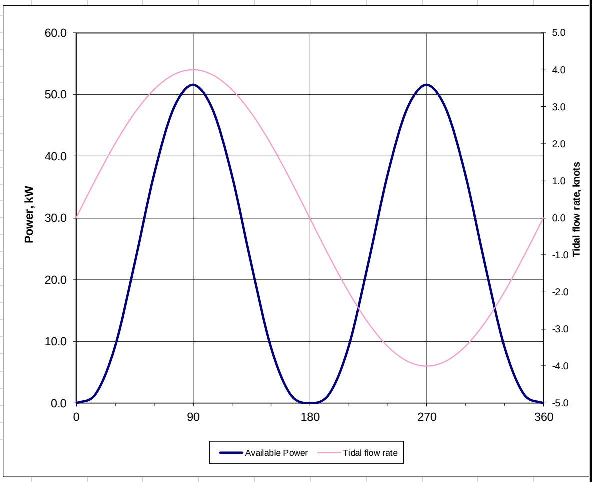
Further Notes
2) The ratio of cumulative power over the 12 hours ~ 0.5 x peak power x 12 hours.
3) To simplify the maths, use 0.5 as a factor when calulating the kWh generated in a tidal flow.
4) Also allow for the spring-neap cycle, which approximates to a halving of the peak flow of a spring tide at a neap tide, whereas the daily cycle stops altogether. For expediancy and simplicity use 0.6 as a further factor.
5) 0.5 x 0.6 = 0.3. It would appear to be about right that a tidal flow would produce about 1/3 of the energy compared to a river running continuously.

Degrees	Sine (degrees)	Open Water speed, Knots	Turbine water speed, m/s	Available Power, kW	Cumulative Available Energy, kWh	Capped Cumulative Energy, kWh
0	0.00	0.00	0.00	0.000	0.000	0.000
15	0.26	1.04	3.16	1.489	0.372	0.372
30	0.50	2.00	5.79	9.180	3.039	3.039
45	0.71	2.83	7.81	22.542	10.970	10.970
60	0.87	3.46	9.21	36.981	25.850	25.850
75	0.97	3.86	10.02	47.681	47.016	47.016
90	1.00	4.00	10.29	51.577	71.830	71.830
105	0.97	3.86	10.02	47.681	96.645	96.645
120	0.87	3.46	9.21	36.981	117.810	117.810
135	0.71	2.83	7.81	22.542	132.691	132.691
150	0.50	2.00	5.79	9.180	140.621	140.621
165	0.26	1.04	3.16	1.489	143.288	143.288
180	0.00	0.00	0.00	0.000	143.661	143.661
195	-0.26	-1.04	3.16	1.489	144.033	144.033
210	-0.50	-2.00	5.79	9.180	146.700	146.700
225	-0.71	-2.83	7.81	22.542	154.630	154.630
240	-0.87	-3.46	9.21	36.981	169.511	169.511
255	-0.97	-3.86	10.02	47.681	190.676	190.676
270	-1.00	-4.00	10.29	51.577	215.491	215.491
285	-0.97	-3.86	10.02	47.681	240.305	240.305
300	-0.87	-3.46	9.21	36.981	261.471	261.471
315	-0.71	-2.83	7.81	22.542	276.351	276.351
330	-0.50	-2.00	5.79	9.180	284.282	284.282
345	-0.26	-1.04	3.16	1.489	286.949	286.949
360	0.00	0.00	0.00	0.000	287.321	287.321

618.930

Ratio of cumulative energy over 12 hours to peak power times 12 hours

0.5



Peak tidal flow rate, knots	3.0			6.0			RMS Sum							
Generator size, kW	Ratio Capped to Available Cumulative Power	Average power generated, kW	Ratio power generated to size of generator	Ratio Capped to Available Cumulative Power	Average power generated, kW	Ratio power generated to size of generator	kWh generated per year	kg CO2 saved at 0.547 kg CO2/kWh	Estimated income 25p/kWh	Estimated Installed cost	Payback, years	Installed cost £k/kWe	Cost p/kWh over 20 years	
1.0														
2.0														
3.0														
4.0														
5.0														
10.0	56.3%	6.643	66.4%	14.3%	8.271	82.7%	65,711	35,944	£16,428	£30,000	1.8	£3,000	£0.12	£0.09
20.0														
30.0														
60.0														

Peak tidal flow rate, knots	2.0			4.0			RMS Sum							
Generator size, kW	Ratio Capped to Available Cumulative Power	Average power generated, kW	Ratio power generated to size of generator	Ratio Capped to Available Cumulative Power	Average power generated, kW	Ratio power generated to size of generator	kWh generated per year	kg CO2 saved at 0.547 kg CO2/kWh	Estimated income 25p/kWh					
1.0														
5.0														
10.0	100.0%	4.052	40.5%	30.6%	7.612	76.1%	53,413	29,217	£13,353	£30,000	2.2	£3,000	£0.15	£0.11

APPENDIX F

Ecological Appraisal

Saunders Energy Ltd,

Power Frame micro tidal turbine

River Arun, Littlehampton

Prepared by

Ed Rowsell, Spatial Ecology

BSc Hons Ecology

June 2015

Summary

- This appraisal is an investigation of the potential ecological impacts of the installation of 4 micro tidal turbines with the River Arun.
- This ecological appraisal consists of a field and desk-based-study to assess the potential for the surveyed area to support protected habitats and species.
- The site consists of a the fully tidal lower stretches of the River Arun before it reaches the sea. The approximate 1km stretch is a heavily modified section of the river, typified by sea defences to protect residential and commercial property, and accommodating busy commercial and recreational boating activity. The overall site does however still contain some typical estuarine intertidal habitats including mudflats and vegetated shingle.
- The proposal site is considered to have zero potential to support reptile, notable invertebrates, badger, dormouse, breeding birds, bats and great crested newts. However potential for impacts has been considered for aquatic mammals, marine mammals, aquatic birds, fish and other marine life.
- Given the scope of the work even with the close proximity of a statutory nature conservation designations, it is highly unlikely any impacts will arise to these designations in relation to this proposal
- The results of the Ecological Appraisal indicate that the proposed works are unlikely to have a negative impact on the ecological value of the site
- This assessment provides recommendations to ensure the proposal can reasonably avoid or mitigate any Impacts on ecology. If the scope of the proposal significantly changes it may be prudent to update this report to ensure it remains valid
- Nature never stands still and with increasing time since this assessment has taken place the reliability of the findings will be reduced. The results of this study are valid for no longer than 2years from the date of this report.

Site context and status

The site consists of the fully tidal lower stretches of the River Arun. The approximate 1km stretch is a heavily modified section of the river, typified by sea defences to protect residential and commercial property, and accommodating busy commercial and recreational boating activity.

The overall site does however still contain some typical estuarine intertidal habitats including mudflats and vegetated shingle. However, the turbines themselves will sit within the subtidal channel.

This section of the River is not covered by any formal nature conservation designations, however at the closest point the Climping Beach Site of Special Scientific Interest (SSSI) of which part of which has also been declared as West Beach Local Nature Reserve (LNR) lies 600m to the south of the proposal.

Description of the proposed development

The proposal is for the installation of 5 Power frame micro tidal turbines measuring approximately 4m by 2m. Units 1 and 2 to be installed on the central piers of the steel span bridge at approximately 50 48'36.4"N 0 33'01.5"W, and units 3,4 and 5 alongside the floating pontoons at approximately 50 48'17.9"N 0 32'35"W.

The turbines will be affixed to the structures and will be positioned in the surface layer of the water. The turbines are encased in 50mm weld-mesh, with an internal clearance of a minimum of 75mm. The turbine blades are symmetrical and will therefore generate power on both the ebb and flood tides. The tips of the turbines will move at around 2.5 time the tidal flow rate.

The power generated will be cable routed to shore based infrastructure to transform and regulate the energy into usable AC power.

Potential impacts assessed

In assessing the potential impact of proposal such as this three stages; commission, operation and decommission need to be considered. Also 2 distinct elements of the proposal need to be looked at separately; the 'wet' element (the turbine itself) and the 'dry' element (the land fall of the cables and other inland infrastructure).

Overall it is considered that the commissioning and decommissioning stages can be scoped out of any further discussion as they are considered to represent a zero or negligible potential for harm to biodiversity. This is due to the scale of the operation; the turbines fitments will be secured to existing structures and will represent the equivalent of a minor repair to a jetty. The deployment and recovery of the turbine is of a similar magnitude as the launching and recovery of a small vessel, and both would be considered de minimis in terms of impacts.

It is also considered that the 'dry' element of the proposal can be scoped out of the need for further investigation. The cable routing and other infrastructure will be attached to existing structures, will not cross any habitats of conservation significance and represent zero risk to protected species.

In conclusion the assessment will focus on the 'wet' aspects for the operational phase of the proposal.

Designated sites

No international protected sites are located within proximity to the proposal. The only statutory designated site within 2km of the proposal is Climping Beach SSSI, which is located at approximately 600m to the south of the nearest turbine installation. The site is designated for its vegetated shingle habitat and an overwintering population of Sanderling *Calidris alba.* The site is currently in favourable conditions for both elements.

Sanderlings are sandy substrate specialists feeding along the tide edge on invertebrates and will roost of sand shingle beaches. It is unlikely they often feed within the estuary and even if they do so there is no mechanism by which they can be affected by the turbine proposal. Only the installation and servicing of the turbines have any potential for disturbing birds, however, Sanderling are known to be tolerant of human disturbance and the effect of the installation and periodic servicing of the turbines will be insignificant in comparison to the background activity in the busy waterside areas.

There is also no mechanism by which the turbine installation can affect the vegetated shingle habitat and on the contrary air pollution is a key threat to this habitat, uptake of renewable technologies will reduce reliance on potentially polluting technologies.

The West Beach LNR included part of the SSSI and also some additional areas on the western side of the river. Similarly to the SSSI no mechanism is identified by which the proposal can affect the site.

It is therefore concluded that while the SSSI is of **national importance** the potential for harm is assessed to be **zero** or possibly indirectly **minor beneficial.**

Habitats

As noted within the wider area a number of priority habitats are present including mudflats, saltmarsh and vegetated shingle. The turbines will be positioned within the subtidal channel and there is no mechanism whereby the operation or servicing of the turbines can affect these habitat. On the contrary as noted above indirectly renewable energy should reduce air pollution and therefore benefit these habitats.

It is therefore concluded that while the habitats present are of **local/county importance** the potential for harm is assessed to be **zero** or possibly indirectly **minor beneficial.**

Fish

The lower reaches of the Arun catchment is known to supoport; Common Roach *Rutilus rutilus,* Flounder *Platichthys flesus*, Sand Goby *Pomatoschistus minutus,* Sea Bass *Dicentrarchus labrax,* Plaice *Pleuronectes platessa* and Solenett *Buglossum luteum.* All of which are common and widespread. There is also known to be populations of migratory fish within the Arun catchment and these species are also of conservation concern. These Species of greater conservation concern includes the European Eel *Anguilla anguilla,* the Sea Lamprey *Petromyzon marinus* and Sea Trout *Salmo trutta.* With the exception of Common Roach and Sea Bass the resident species are largely demersal (living and feeding on the sea bed) in their habits and can be considered unlikley to be impacted by the proposals. Common Roach, Sea Bass and the migratory species Sea Trout, will tend to feed and transit higher in the water column and may bring them potentially into the path of the

turbines. It is not clear at what level in the water column Sea Lamprey and European Eel may move through the catchment therefore for the purpose of this exercise it is assumed they may pass through the level of the swept path of the turbines

Fish injury and mortality has been investigated using similar technology by the Electric Power Research Institute Report 'Evaluation of Fish Injury and Mortality Associated with Hydrokinetic Turbines' in November 2011. For a range of water velocities and fish size classes the measures immediate and total (48 hours after test) fish survival rate averaged 99%, with an average 95% of the sample passing through with no visible damage. It should be noted study fish were introduced directly into the turbine plume so were prevented from avoiding the turbines. Fish have well developed senses to avoid obstructions and will detect the pressure change caused by the turbine blade and it is anticipated they will avoid the device altogether. The 50mm mesh guards will also stop larger fish that are more likely to be damaged from entering the turbine and the 75mm clearance between the turbine blades and the mesh means it is highly unlikely that fish will be 'pinched' between the blade and guard. Therefore only smaller size classes of fish have the potential to pass through the swept path of the turbines, migratory Sea Trout are unlikely to fall into this category, but Sea Lamprey, European Eel, juvenile Roach and juvenile Sea Bass could potentially enter the turbine.

It is also noted that the water that will be passing directly through these devices will be minimal compared to the volume of water passing along the channel. Most migratory fish will tend to 'run' at higher states of the tide, but in a worst case scenario assuming no avoidance the channel is between 60-70 wide at low tide and therefore even if fish we only moving within the top 2m of the water column, only 5.7-6.7% of the channel is within the swept path of a single turbine.

With a combination of avoidance behaviour, the un-swept volume of water passing up and down the river corridor and the inherent high fish survivability passing through this type of technology, it is felt the effect of the turbines on the fish populations is likley to be negligible and will not represent an obstacle to fish passage.

It is therefore concluded that while the migratory fish population would be considered of **national importance** in this location the potential for harm is considered to be **negligible.**

Marine life

It is possible to identify a few ways in which the turbines could affect marine life, including mobilising sediments through increased turbulence, mechanical damage to free swimming animals and the introducing of polluting substances.

Sediments:- Due to the height above the seabed it is not anticipated that the turbine will create any scouring and mobilisation of sediment. In this heavily modified stretch the sediment is already fairly mobile and dredging and wash from vessels will be more significant than any effect from the turbines.

Mechanical damage:- It is not anticipated that benthic organisms will be affected at all by the turbines, however, free swimming species may pass through the swept path of the turbines. However it is considered that this will largely be planktonic life and is highly unlikely to be affected.

Pollutants:-It is proposed that at least initially the turbines will not be treated with antifouling materials and will instead be periodically cleaned to remove fouling. Even should anti-fouling have to be applied sometime in the future, the materials will be approved for marine use and the levels will be insignificant compared to the usage upon recreational and commercial vessels. Any lubricants and other materials will be approved for marine use and again will be de minimis compared to the background boating activity.

The lower stretch of the river is not identified as being of any particular marine life interest and is already heavily modified, subject to periodic dredging and heavily used by boat traffic. It is therefore considered that it is unlikely that any effect on marine life will occur.

It is therefore concluded that the marine life would be considered of **site importance** in this location the potential for harm is considered to be **negligible.**

Overwintering and foraging bird

The nearby Climping Beach SSSI is designated for its over-wintering population of Sanderling and it is likely that a range of shorebirds, seabirds and wildfowl will use or pass through the estuary. The mechanisms identified for harm include disturbance of feeding birds during installation and servicing operations and mechanical damage to birds.

Disturbance:- as discussed above in the designated sites section it is anticipated that birds feeding in the estuary will be used to human activity and operations in relation to the turbines will be insignificant.

Mechanical damage:- without adequate shielding the turbines would represent a risk to diving birds or water surface feeding species. However with the mesh guards in place there is no mechanism whereby feeding birds can be affected.

It is therefore concluded that while the overwintering and foraging bird interest is of **local/national importance** the potential for harm is assessed to be **negligible.**

Aquatic and marine mammals

Aquatic mammals could be affected by mechanical damage in the turbines and marine mammals are sensitive to acoustic disturbance transmitted through water.

Turning first to the aquatic mammals; otter and water vole are both protected species and are known to occur within the wider area. However the habitat is entirely unsuitable for water voles and they do not need to be considered further. Otter which is a European protected species protected under the Conservation of species and Habitats Regulation 2010, may now be present in the Arun catch and will use tidal stretches of rivers, but it is highly unlikely that otters will make anything other than transient visits to busy waterways such as this. There is a very low likelihood that aquatic mammals will come into conflict with the turbines and the guarding will prevent any harm should they interact with them.

Moving to marine mammals Common/Harbour Seals are known to occasional visit the Arun catchment, however the nearest colony is within Chichester Harbour which is around 35km by sea. Cetaceans sightings are very rare in the English Channel species such as Harbour Porpoises are the most common sightings and the most likely to enter a river system. It is however a very rare occurrence and it is unlikely the acoustic effects from turbine will be significant compare to other sources.

It is therefore concluded that the aquatic and marine mammal interst is of **local/national importance** the potential for harm is assessed to be **negligible.**

Terrestrial mammals and bats

The proposals represent no possible potential for impacts upon bats and other terrestrial mammals. No suitable habitat is present and no mechanisms for harm have been identified.

Breeding birds

The site and particular areas to be affected by this proposal were found to contain no suitable habitat for breeding birds and there is zero likelihood that this proposal will affect any breeding bird species.

Reptiles

The site and particular areas to be affected by this proposal were found to contain no suitable habitat for reptiles and there is zero likelihood that this proposal will affect any reptile species.

Amphibians

The site and particular areas to be affected by this proposal were found to contain no suitable habitat for protected amphibian species and there is zero likelihood that this proposal will affect any interests in these taxa.

Notable invertebrates

The site and in particular the areas to be affected by the development does not contain any habitats likely to support notable invertebrates and there is zero likelihood that this proposal will affect any interests in these taxa.

Conclusions

All possible impacts of this development have been investigated and it is possible to conclude that the project represents a very low risk to ecological receptors. The only slight concern is for the migratory fish populations that pass through the catchment, however it would appear that at the current scale of operation a significant effect is highly unlikely. Within the current scope and scale of the project no significant ecological impacts are anticipated and the project will contribute to renewable energy targets aimed at tackling climate change.

Personnel

Ed Rowsell is a professional ecologist, ornithologist and GIS expert with 20 years post graduation experience, 7 year of which were spent at Chichester Harbour where he built up a wide range of knowledge and experience of the coastal environment. Including developing, initiating and leading numerous monitoring, surveillance and research programmes including; the Chichester Harbour Small Fish Surveys in collaboration with Sussex IFCA, the Solent Seal Tagging Project in collaboration with Hampshire and Isle of Wight Wildlife Trust, Greenshank Geolocator project in collaboration with Farlington Ringing Group and led the development of the Solent Goose and Wader Watch online recording system. From various roles he has a broad range of regulatory process experience from both the regulator and applicant side including; EIA, Appropriate Assessment, Planning Consent, Marine and Coastal Access Act licensing and SEA.

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