Archimedean Screw Hydropower scheme at Guyzance Meander

Design Description

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Executive summary

An Archimedean screw has been chosen as the most suitable technology for the natural resource at this site. Control philosophy and design are predicated on maintaining compliance with the scheme environmental conditions. Key parameters are:

Net head: 5.20m

Length: ~16m (flights ~11m)

Maximum flow: 2.90 m3/s

Diameter: 2.60m

Number of flights: 4

Maximum rotation speed: <=24 RPM

Maximum power: 100kW

Predicted average annual energy output: 375,000 kWh

Predicted average annual CO_2 emissions saved: 161.25 t/CO_2

Introduction

A number of quite different types of machinery can be used to generate hydroelectricity. The present document explains the principles of hydropower, some common distinctions between types of site, the choice of different equipment types, considerations specific to the Archimedean screw system chosen for this site, and a technical specification for the screw.

This document deals primarily with general principles and how these have been applied to design the proposed scheme at Guyzance. Detailed consideration of wider impacts and mitigations is developed in the supporting document set.

Physics of hydropower

Hydroelectric power requires that water must fall over a height. Energy is captured from the falling water. Note therefore that wave or tidal power are NOT generally described as hydroelectric power.

To capture energy from falling water, it is necessary to intercept it with a generating device at a point where the water can fall. This means either:

- finding an existing fall in height, such as a dam, weir or waterfall - or
- creating a fall in height, by constructing a weir, and/or
- causing water to flow out of the river, and leading it onward at a gentler downward slope than the main river, to a point where it is now higher above the main river.

Two main factors govern the energy which can be captured:

- Head: the height which the water can fall at this spot (in metres)
- Flow: the rate of water passing this spot (in tonnes per second or m^3/s)

Note that flow is NOT speed or velocity. The same flow will move quickly through a narrow channel and slowly through a wide channel. Velocity (in m/s) is flow divided by cross-sectional area. Velocity of the water will vary as it moves through the channels, and must be controlled by design of new channels so that it remains within limits which avoid detriment.

The total power (in kilowatts kW) which could be exerted by falling water in a perfect system would equal the head times the flow times the force of gravity. In an imperfect world it is not possible to convert all that power into usable electrical power, so the shortfall is represented by an efficiency percentage. In micro-hydro this has often been found to be around 70%.

[equation: Power (kW) = Head (m) x Flow (m^3/s) x gravity (9.81 m/s^2) x efficiency (70%)]

Therefore the maximum power which a system can achieve (its rated capacity) depends on the fall (head) and the quantity per second (flow) which can be taken in a state when these are at their highest values.

Power vs energy

Power expressed in the terms above is a measure of just how big the system is – its capacity to generate. As such it does not tell us how productive the scheme is. A simple illustration in familiar terms might be the demand of an electric kettle: it may have a rated power of 1kW, but it consumes no electricity until it is actually switched on.

Similarly a hydropower scheme may have a rated power of 100kW - based on having been designed to drop a certain flow down a certain head at a certain efficiency. But the turbine will produce nothing each day unless the water flow is present. Therefore good design of the scheme ensures the turbine is positioned and sized to take a prudent amount of water which will regularly be present.

The kW power rating of a scheme is therefore a useful indicator of its relative size. However, for energy planning and for assessing profitability, what is far more important is how much energy a system actually produces each day or each year. This output is measured in kilowatt-hours (kWh), which is what we pay for in our electricity bills. It will be appreciated that a well-designed or well-situated hydro system with a low rated capacity (max kW) could produce more electricity each year (kWh) than a system nominally bigger in kW terms but which lacked the expected water flow.

For this reason, judging the merits of generation schemes based on their maximum rated power (kW) can lead to perverse outcomes. Considering their actual productivity (kWh) is to be preferred. Calculation of CO_2 savings is also based on the latter.

The importance of site to equipment choice and impacts

For wind turbines, efficiency means siting them in locations where they can be reliably reached by non-turbulent wind and designing them for the windspeeds prevailing there. The equivalent considerations for hydropower are that there is a fall in height and that a certain flow can be expected to be present often enough to make the choice of a particular turbine size worthwhile.

With hydropower, rarely is the choice of a site driven by speculative interest from an investor who has flexibility as to which location is exploited. The far more typical case is that a specific site is being considered for development by its owner, who has realised it has potential for hydropower. In such cases the landowner proposes to economically exploit property in a way which that this specific site particularly favours, rather than a generic commercial project whose location is a matter of negotiable preference. This has a bearing on the consideration of “better alternative sites” in planning terms, which are not available to such owners.

Sites may be differentiated simply into those which are high-head and those which are low-head. This distinction is important because the two extremes dictate the use of different machinery and have different layouts, placing different emphases on their environmental impacts. An applicant has one or other type of site, and must make decisions accordingly.

A word must be said about high-head sites, as these have created a widely-held stereotype of hydropower and have influenced prevailing assumptions. High-head schemes may involve creation of new dams to obtain head, which in the very largest cases can be responsible for major ecological changes and social impacts. High-head schemes in the UK tend to be modestly sized and bring water inside a pressure pipe down to a turbine house. The turbine (and house) can be small, because flow can be small if the head is large. Small high-speed turbines such as Turgo and Pelton wheels and some Francis designs are used. Pressure effects and pipe integrity are important. Where schemes require water to be led long distances to achieve the desired head, environmental impacts may include long reaches of watercourse being depleted of its natural flow, and long access roads to maintain remote structures. Pressure pipes and high-speed turbine rotation mean vertebrates must be totally screened out, and particles will damage the equipment if not filtered out. However, on short and fishless upstream streams, ecological impacts may be more limited.

The present site is low-head, with a fall of less than 10m. Low-head schemes typically do not create new dams to artificially hold back the flow: these are called run-of-river, whereby flowing water is abstracted from a river to fall through a system and back to the watercourse. As the head is so much lower, more flow must be taken to obtain a viable output. This means that channels/pipes and the turbine and powerhouse may need to be somewhat larger.

Turbine types suitable for low-head may include crossflow, Francis, Kaplan and other propeller types, Archimedean screws, and waterwheels may also appear in use. The fineness of screening will have an impact on performance. Pressure is not a consideration and fine screening may be dispensed with in the case of devices which regulatory authorities have decided are relatively harmless for fish to move through (Archimedean screw, waterwheels). Distances may be shorter and overall footprint smaller than for high-head, but the watercourse is depleted of more water for a shorter distance. Lowland river habitats are often rich in fish, and regulators often favour improvement. Schemes must often demonstrate they will conserve or improve conditions for fish to inhabit and pass the site.

Frequently it is the case (particularly with low-head) that the site in question is prone to flooding. This is unsurprising, as hydropower installations are the technical successors of watermills, which in order to derive their power from the river must by their very nature lie within or close to its flood corridor. The argument must be that this is truly water-compatible development, in the same way as water-treatment infrastructure which requires proximity to the water which it must treat. As a general rule it should be noted that an installation which is designed to make use of a head of water at a weir is therefore by definition located at a fall in the terrain. The behaviour of flood water will differ by site, but it is unlikely to be higher below the fall than above. Schemes taking smaller flows will tend to make less imposition, but mitigation should be proportionate to any risk which is assessed. (Schemes where size or ecological constraints preclude the use of pressure pipes can only be located within the flood zone, as to convey water outside it would simply extend the zone.)

Where the applicant is committed to a single site, it has most often been possible to agree some viable means of mitigation for potential impacts which the scheme may pose. Thus environmental regulators will look most favourably on scheme which best meet their aims. At Guyzance, the EA will be keen the scheme does all it can to protect flow and fisheries. The present design makes the most modest demands on river flow for a still viable scheme.

Choice of the Archimedean screw

The Archimedean screw has been used as a hydropower device only since 1997. It has been widely adopted in Europe, with around 120 schemes operating in the UK. The geometry of the screw limits its application to low-head sites of between 1m and c.10m head.

The screw is a physically larger device than its competitors for achieving the same power. The screw diameter, and the cross-section (width and depth) of the intake and outflow channels, sluice gate, and intake screen, are dictated by the design flow. The screw is installed at a technically-optimum standard inclination (~22 degrees) from horizontal, and it must span the vertical head between the upper and lower water levels. Therefore the screw's length is derived from the head (by trigonometry: the head height divided by the sine of the angle). Angle of inclination may varied slightly by design. Maximum rotation speeds are never more than some 30 RPM, which is very much slower than all competing devices.

This large size confers benefits. The water passing through it is open to air, and is subdivided into fairly large and slowly-rotating subsections of the device. This means that the screw can both convey large debris without damage and can convey fish unharmed downstream through its full length. This has the important benefit that even the water which is taken to flow through the hydropower system continues to be available to the ecosystem. Therefore no fine screening is required, and coarse screening alone is acceptable, which minimises the extent to which screening obstructs the flow and reduces the system's output.

While its closest technical competitor the Kaplan may offer a better textbook efficiency before screening requirements are imposed, the screw's performance after screening and its passability to fish mean that it is often preferred to the Kaplan at sites where either might be viable. The "water to wire" efficiency of a screw installation (see equation above) can often reach 75%- 80%. Variable-speed control systems are often a worthwhile enhancement and these seem likely to give even better conditions for fish passage.

Not even a screw can convey fish upstream. It is for other aspects of design to maintain or improve existing upstream passage for fish. Great attention is paid to mitigating this impact. In the present project, proposed impacts on flows are modest. Importantly also, the attraction of fish to the discharge is minimised by having a slightly excavated bay to slow the outflow.

Scheme layout constraints

The potentially usable head at the present site is across the neck of Guyzance Meander. Where a screw is used, this must be installed to descend an incline between an upper water level and the tailwater. It is therefore necessary to bring the inflow to a point at the top of the screw. This requires the creation of an intake through the neck of the meander. A piped design is proposed, controlled by a sluice gate, with an intake screened against debris at the west bank of the meander. A powerhouse will be constructed over the electrical equipment at the top end of the screw, to be made waterproof against flood levels. The screw will descend the bank slope at the east side of Guyzance Meander directly to the river.

Technical specification

Site measurements have concluded that the layout above will serve a screw with a net head of 5.20m. The total length of this device will be some 16m of which the flights of the turbine occupy some 11m. To ensure no detriment to fisheries, it is proposed to take a maximum flow of 2.90 m3/s which places only a modest demand on the available flow in the river, and ceasing operation in low flows. This regime will require a 4-flight screw with a diameter of c.2.60m at maximum speed <=24 RPM. These parameters create a system capable of producing up to 100kW when operating in optimal conditions. Analysis of likely operation over the average year predicts an average annual output of around 375,000 kWh. Against conventional alternatives, this predicts an average annual saving of 161.25 tCO_2 emissions.

Design of ancillary systems

A bespoke variable-speed control system will be used which will allow the screw to operate down to a low speed therefore always keeping the screw's chambers fully filled with water. This is preferable for fish movement and for minimising system noise as well as having been calculated to optimise energy capture. Submerged pressure sensors in the river will give a positive signal to allow the system to operate whenever agreed conditions are met. The intake sluice gate is of a proven design which will passively fall closed to shut off inflow and is opened by a hydraulic system with feedback controls. All instrumentation and operation is controlled by a PLC using purpose-written software and presented to operators via a touchscreen in the powerhouse and/or remotely via a web screen. Control philosophy and design are predicated on maintaining compliance with the scheme environmental conditions.