The University Of Sheffield.

E-Futures

Mini-project summary report

Efficiency of Micro Hydro Power

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Abstract: Theoretical and experimental methods to monitor the long term efficiency of a reverse Archimedes screw installed on the River Goyt were investigated. Slug injection dilution gauging using Rhodamine WT provided a means of experimentally determining the volume flow rate of the River Goyt at New Mills. However there is uncertainty as to the accuracy and repeatability of these preliminary results and as such further investigation is required. Relation of the measured flow rate to the mean daily water level monitored by previously installed pressure gauge sensors potentially allows the volume flow rate passing through the turbine and hence the long term efficiency to be monitored. Theoretical flow modelling techniques also allow an adequate estimation of the river flow rate at New Mills to be obtained. However the approximations made to convert this to the volume flow rate that is passing through the turbine, introduces great uncertainty in the results.

1. Introduction

As the European Union sets ever more stringent policies regarding the composition of the worlds future energy mix, i.e. 20% of energy from renewable sources by 2020, [1] decentralised energy production becomes an ever more economically feasible reality.

Hydro power offers many advantages when compared to other forms of renewable energy, not least a more consistent, efficient and robust technology. With ever-increasing incentives through the means of feed in tariffs, there is mounting interest in community owned micro hydro schemes.

Micro hydro power is a term used to refer to hydro power schemes with an installed capacity of <500kW. [2] These schemes tend to be "run-of-river" installations i.e. a small weir is all that is required with little if any water storage, hence micro hydro has a much less significant impact on the environment than its large scale counterpart. [3]

Torrs Hydro is the UK's first community owned micro hydro scheme, they have a 63kW reverse Archimedes screw installed on the River Goyt at New Mills, High Peak, Derbyshire.

An Archimedes screw consists of an array of helical blades adjoined to a central axis. It is generally assumed that the weight of the water enclosed by the screws blades provides the basis for the rotation of the screw and hence drives its operation. However Muller [4] suggests most of the water weight rests on the immovable trough and very little is responsible for driving the screw. [8] Instead Muller suggests that between each successive blade, a head difference exists and this leads to the development of a hydrostatic force along the screw. This force acting in the direction of the helical rotation is what drives the screw.

The power output of a micro hydro scheme can be determined from

$$P=\eta \rho g Q H$$

Where P is the mechanical power output (W), η is the hydraulic efficiency of the turbine, ρ is the density of water (1000kg/m^3), g is the acceleration due to gravity (9.81m/s^2), Q is the volume flow rate passing through the turbine (m^3/s) and H is the pressure head across the turbine (m).

Conversely if the power output, volume flow rate through the turbine and head of the weir be known, the hydraulic efficiency of the turbine can be calculated.

Hourly power data is available from Torrs Hydro, whilst the head of the weir can be taken as 3m as specified by MannPower who installed the screw. [5]

This study will investigate three potential methods for the long term monitoring of the volume flow rate passing through the Archimedes screw. These are; standard weir discharge equations, dilution gauging and theoretical flow estimation.

2. Weir Discharge Equations

Standard weir discharge equations allow a gauged upstream head (water level) to be converted to a volume flow rate. As such two pressure gauge sensors were installed on site to continuously monitor the water level in the river.

The first pressure gauge is positioned above the broad crested weir where the Archimedes screw is installed, between the turbine inlet and the weir crest.

Therefore it is effectively monitoring the volume flow rate bypassing the screw. The second pressure gauge is located above a crump weir downstream of the turbine exit and therefore is effectively monitoring the total volume flow rate of the river. The volume flow rate passing through the turbine can then be estimated by subtracting the flow rate passing over the broad crested weir (pressure gauge 1) from the total river flow (pressure gauge 2).

The results obtained from this method appeared grossly inaccurate. The mean flow rate estimated to be passing over the broad crested weir was $11.82m^3/s$, whilst the total river flow was estimated at $23.96m^3/s$. Historical flow data for Marple Bridge an Environment Agency (EA) gauging station 5 miles downstream of New Mills, suggests a flow rate of $8.165m^3/s$ is exceeded only 10% of the time in the River Goyt. On this basis it was deemed this method was inappropriate for the long term flow monitoring at New Mills. [6]

3. Dilution Gauging

It was theorised that dilution gauging could be used as means of calibrating the two pressure gauge sensors so the monitored water level can be related to the volume flow rate passing over the pressure gauge. The volume flow rate passing through the turbine can then be estimated by subtracting the flow rate passing over the weir (pressure gauge 1) from the total river flow (pressure gauge 2).

Slug injection dilution gauging using fluorescent Rhodamine WT dye was performed on the River Goyt at New Mills. Pre-calibrated Self Contained Underwater Fluorescence Apparatus (SCUFAs) were used to detect the dye and hence the concentration in the river was determined. Four litres of 0.1% Rhodamine WT in tap water was injected into the river and detection was performed 390m (assumed sufficient for cross-sectional mixing) downstream. As long as this is the case, the volume flow rate of the river can be calculated using

$$Q_{river}=(C_iV_i)/\int(C-C_b)dt$$

Where Q_{river} is the volume flow rate in the river (l/s), C_i is the concentration of tracer injected (l/l), V_i is the volume of tracer injected (l), C is the concentration of the tracer measured downstream, C_b is the background concentration in the river (l) and t is the time (s). The integral therefore represents the area underneath the peak corresponding to the tracer slug in a plot of $C-C_b$ against time.

The results (Table 1) were compared with the mean daily flow rate monitored at the EA's Marple Bridge gauging station. The flow rates calculated from the dilution gauging are comparable to those seen at Marple Bridge, all be it always slightly higher. This most likely being due to limitations in the method which include; difficulty in accurately measuring fluorescence in a turbid river, inconsistent background readings for the rivers natural fluorescence and the low concentrations of Rhodamine being dealt with.

It should also be noted the flow rates calculated from the two SCUFAs (positioned ~3m apart) did not match suggesting uniform cross sectional mixing hadn't occurred. Should this be the case, it could potentially be resolved by performing multiple instantaneous injections across the river at the injection site.

Table 1 – Comparison of the flow rates calculated using slug injection dilution gauging and the mean daily flow rate gauged at Marple Bridge.

	SCUFA 060 (m^3/s)	SCUFA 689 (m^3/s)	Marple Bridge[1] (m^3/s)
Day 1	3.16	No data recorded	2.48
Day 2	2.59	3.25	Not available
Day 3	9.75[2]	2.65	2.20

[1]Contains Environment Agency information © Environment Agency and database right

[2]Result deemed an erroneous result on the basis of a laboratory control check.

4. Theoretical Flow Modelling

A theoretical estimation of the flow rate at New Mills can be obtained using a method outlined in a technical report by Sheffield Renewables. [7] The actual volume flow rate passing through the turbine can then be estimated from

$$Q_{turbine}=Q_{New\ Mills}-Q_{95}$$

Where $Q_{turbine}$ is the volume flow rate passing through the turbine (m^3/s), $Q_{New\ Mills}$ is the estimated volume flow rate in the river at New Mills (m^3/s) and Q_{95} is the flow rate exceeded 95% of the time in the River Goyt as monitored by the EA's gauging station at Marple Bridge.

The flow data was then used to calculate the long term efficiency of the Archimedes screw for the 2009 calendar year.

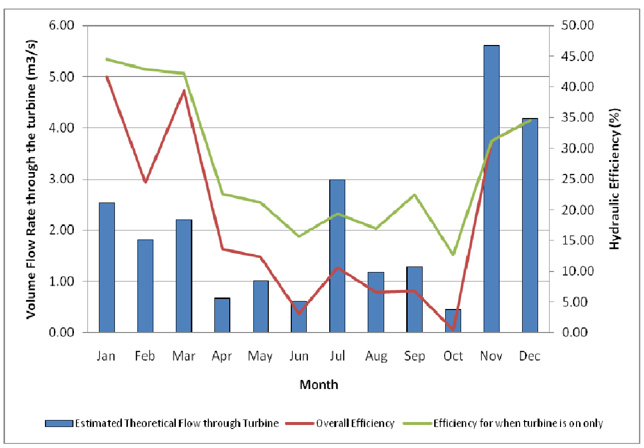
Unsurprisingly the efficiency of the Archimedes screw appears to be dependent on the volume flow rate passing through the turbine (Figure 1). This is to be expected since the screw is an example of a fixed speed turbine.

However the calculated efficiencies were much lower than expected for a micro hydro scheme, they ranged from <10-50% with a mean efficiency of just 19%. Further investigation into the screws power output and calculated capacity factor yielded an explanation. The screw was operating with a considerable amount of downtime. Therefore in order to get a better approximation of the screws efficiency, the data was reanalysed using only data where the screw was operational for some part of the day.

This resulted in the mean efficiency increasing to 32%, an improvement, but still well below the 60-80% efficiency expected for micro hydro schemes. [3]

There are site specific reasons which could explain the screws lower than expected efficiency; head reduction, complex hydraulics at the inlet and outlet etc. However it must be emphasized the most likely reason for the calculated low efficiency is the approximation made to determine the volume flow rate passing through the turbine.

Figure 1 – A graph showing how the estimated theoretical flow rate through the turbine and the resulting calculated hydraulic efficiency changes throughout the 2009 calendar year.



5. Conclusions

The use of standard weir discharge equations in combination with installed pressure gauge sensors does not provide a reliable means of determining the volume flow rate in the river. This can be attributed to the historical nature of the weirs in question and the inability to accurately determine the relevant discharge coefficients.

On the other hand slug injection dilution gauging using Rhodamine WT does show some initial promise as a means of accurately determining the flow rate in the river. Combing accurate flow measurement over a range of flows, with the installed pressure gauge sensors could therefore yield a long term means of monitoring the volume flow rate passing through the turbine. However, it should be noted the slug injection method itself still needs to be refined as it too has limitations.

It can also be concluded that the flow rate at New Mills can be predicted with reasonable accuracy using a flow modelling method specified by Sheffield Renewables. However, conversion of the estimated river flow rate to that which is actually passing through the turbine by subtracting the rivers Q_{95}, introduces great uncertainty. The efficiencies predicted using the flow modelling method are lower than expected for a micro hydro power scheme and do show some dependence on the volume flow rate passing through the turbine.

There are possible explanations for both these observations but the biggest contributor is most likely to be misestimating the volume flow rate passing through the turbine. As such dilution gauging or another accurate means of measuring river flow rate in combination with the installed pressure gauge sensors is seen as the only way to accurately monitor the long term efficiency of the screw.

6. Future Work

Future work will focus on the optimisation of the slug injection dilution gauging method, determining the ideal quantity and concentration to inject depending on the flow conditions. If uniform cross sectional mixing remains a problem or consistent reliable results are not obtained other flow measurement techniques will be investigated.

Once confidence in the flow rate measurement has been obtained, the construction of calibration graphs relating river flow rate to water pressure/level can begin. This will require further site visits throughout the year to allow accurate flow measurement to be carried out over a range of flow rates. The calibration graphs will provide a long term means of monitoring the volume flow rate passing through the screw and hence its efficiency.

7. References

[1] The European Parliament and the Council of the European Union; Directive 2009/28/EC on the promotion of the use of energy from renewable sources; Official Journal of the European Union; L 140; 2009; 16-61.

[2] O. Paish; Micro-hydropower: status and prospects; Proceedings Institution of mechanical Engineering; 216; Part A: Journal of Power and Energy; 2002; 31-40.

[3] A guide to UK Mini Hydro Developments; The British Hydropower Association; January 2005; version 1.2.

[4] G. Muller and J Senior; Simplified theory of Archimedean screws; Journal of Hydraulic Research; 47; 5; 2009; 666-669.

[5] Details of the New Mills project can be found on the MannPower website at http://www.mannpower-hydro.co.uk/casestudy.php; Last visited 07/02/11.

[6] 69017-Goyt at Marple Bridge Gauged Daily Flow; National River Flow Archive Data Retrieval Service; Centre for Ecology and Hydrology; Can be requested at http://www.ceh.ac.uk/data/nrfa/data/access_data.html; Last visited 08/02/11.

[7]R. Collins; Hydro Project Technical Report Summary of 2008; Sheffield Renewables; Available at http://www.sheffieldrenewables.org.uk/resources/; Last visited 10/02/11.