Noise emissions from two tidal turbines; an experimental field campaign

Schmitt, P., Pine, M. K., Lieber, L., & Kregting, L. T. (2021). Noise emissions from two tidal turbines; an experimental field campaign. In *The 14th European Wave and Tidal Energy Conference (EWTEC) 2021: Proceedings* (pp. 2204-1-2204-4). (The European Wave and Tidal Energy Conference (EWTEC): Proceedings). https://proceedings.ewtec.org/product/ewtec-2021-plymouth-uk/

Published in:
The 14th European Wave and Tidal Energy Conference (EWTEC) 2021: Proceedings

Document Version:
Peer reviewed version

Noise emissions from two tidal turbines; an experimental field campaign

Pál Schmitt, Matthew K. Pine, Lilian Lieber and Louise T. Kregting

Abstract—**The first tidal turbine arrays have now been installed as the world strives to reach net zero carbon targets by 2050. Underwater noise emissions from single tidal turbine devices have caused some environmental concern in the past and therefore determining levels of noise emitted from these structures has become a crucial component of the consenting process. Ecological concerns include auditory masking for local fauna, presenting potential migration barriers and affecting predation. While some progress has been made in characterising noise emissions from individual tidal turbines in realistic field conditions, little is known about the noise field created by multiple turbines. This paper presents a first analysis of the variation of noise emissions of an array of two test turbines, deployed from a moored floating platform in the Strangford Narrows, Northern Ireland. Data was acquired using a drifting hydrophone for zero, one and two turbines operating under different control settings. Data analyses were complicated by the limited amount of data. Stopping the turbines completely does not necessarily result in minimum noise emissions, potentially due to flow separation from the stationary blades, turbulence and induced structural vibrations.**

Keywords—**Acoustics, Hydrokinetics, Renewable Energy**

I. INTRODUCTION

The addition of underwater noise from anthropogenic sources such as marine renewable energy developments should be carried out in a conscious manner considering the potential of noise interfering with an animal's auditory function [1]. The emission of sound by single wave and tidal energy converters have been measured and characterised in situ for some devices, e.g. [2-6]. The acoustic frequency range emitted during operation extends from 1Hz to 10kHz [7]. The current consensus is that a single device is unlikely to cause acoustic injury to marine animals [6-10]. As the world strives for net zero carbon targets, the race is on for substantial input by the marine renewable energy sector, with the first arrays already operating. However, how arrays of renewable energy structures impact the underwater soundscape is unknown.

Underwater sound from turbines is attributed to multiple components including the gear box [4], mooring chains [3], tether [5], hydraulic pumps during start-up and shut down for a wave energy converter [10] and tidal blades [4]. Source levels from the various components will vary depending on turbine design and local environmental conditions at the time of measurement [6]. Assessing how the noise propagates when multiple devices are operational is far more complicated with the potential for interference and cancellation of some frequencies [11]. Understanding the noise emissions from multiple devices in dynamic environments is therefore important when assessing the impact on animals in the area for the consenting process. Failure to do so may underestimate the true acoustic impact zones from turbine arrays [12].

To date, most empirical research on tidal energy device noise has been limited to single turbines e.g. [2-6, 8-10]. Here we took advantage of the TTT3.5 field campaign testing two horizontal axis tidal turbines (HATT) from a moored platform in the Strangford Narrows. This paper presents the noise emissions of different testing configurations from these field trials establishing the first characterization of noise emissions of an array in realistic operating conditions.

II. MATERIALS AND METHODS

A. Study site and turbine type

Assessment of the noise produced by the sub-sea turbine devices was carried out in the Narrows tidal channel, located in Strangford Lough, Northern Ireland, UK (N 54°22'54.48"N, 5°33'24.274"W). The seafloor at the

P. Schmitt is with the School of Chemistry and Chemical Engineering, Queen's University Belfast, Queen's Marine Laboratory, 12-13 The Strand, Portaferry, Northern Ireland, UK (e-mail: p.schmitt@qub.ac.uk).

M. K. Pine is with Ocean Acoustics Ltd, P.O. Box. 31306, Milford 0620, Auckland, New Zealand (e-mail: matt.k.pine@outlook.com).

L. Lieber is with the School of Chemistry and Chemical Engineering, Queen's University Belfast, Queen's Marine Laboratory, 12-13 The Strand, Portaferry, Northern Ireland, UK (e-mail: l.lieber@qub.ac.uk).

L. T. Kregting is with the School of Natural and Built Environment, Queen's University Belfast, Queen's Marine Laboratory, 12-13 The Strand, Portaferry, Northern Ireland, UK (e-mail: l.kregting@qub.ac.uk).

location of the testing site is characterised by cobbles and small to large boulders on a bedrock base layer with flow rates reaching approximately 2 m/s [13].

The turbine devices were mono-strut HATTs submerged at 1.5m hub depth. Full details on these devices can be found in [14]. The turbines were mounted on two joined floating barges with a 10 x 4m surface area and 0.75m draught. A 5m gap between the connected barges provides a total testing area of 10 x 5m area (Fig. 1). A flexible stem acoustic doppler velocimeter (ADV) (Nortek AS, Norway) was mounted on the trusses and captured the horizontal u, lateral v and vertical w velocity components to record inflow conditions at 16Hz for 600s for each configuration.

B. *Turbine noise levels*

Acoustic measurements of the underwater noise of the two HATTs were carried out on the 27th July 2018 on a flood tide. Weather conditions were classified as fair (World Meteorological Organization sea-state 0-1). A drifting hydrophone system was used consisting of a SoundTrap 300 HF autonomous recorder (ST300HF, Ocean Instruments Ltd, New Zealand) that was connected securely to a leaded rope and suspended 2m below the sea surface from a connected buoy. The sampling rate was set at 288kHz. Multiple drift sampling profiles were carried out from the platform by placing the hydrophone into the water and allowing it to drift 50m downstream of the platform. Three drifts were carried out for each turbine test configuration (Table 1).

C. *Analysis*

Each drift sample resulted in a single audio recording. Spectrograms of each recording were generated and used to determine the time at which the hydrophone started and stopped drifting. Spectra were also generated for each of the configurations for the last 10s of drift time.

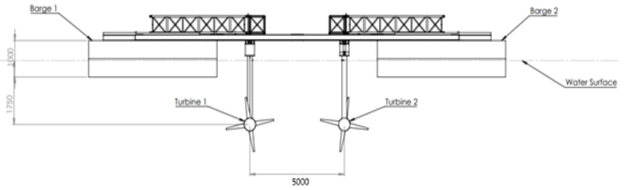

Fig. 1. Experimental platform setup with the two barges, gantry mounting and turbines.

III. RESULTS

Table 1 provides an overview of the test programme, including both turbines, one turbine or braked turbines with the associated mean revolutions per minute (RPM) and mean flow speeds for each drift profile. Mean flow speed ranged from 0.91 to 1.49 m/s during the measurement campaign showing deviations in response to the changing tide. Slight variations were observed in RPM between the three runs for each test programme. Braking the turbines doesn't completely stop them, so even when the turbines were braked, some low RPM was recorded.

TABLE I
TESTING PROGRAMME WITH MEAN REVOLUTIONS PER MINUTE (RPM) AND MEAN FLOW SPEED ± STD

No. Turbines	Mean RPM	Mean Speed (m/s)
Both	70.07 ± 0.95	0.91 ± 0.06
	70.07 ± 1.61	1.10 ± 0.07
	70.17 ± 6.29	1.13 ± 0.12
Both	84.86 ± 8.43	1.03 ± 0.08
	90.06 ± 1.09	1.02 ± 0.08
	89.96 ± 1.0	1.03 ± 0.06
One	90.05 ± 1.04	1.23 ± 0.09
	89.90 ± 1.36	0.72 ± 0.24
	89.87 ± 1.11	1.34 ± 0.12
Braked	6.30 ± 1.04	1.43 ± 0.13
	5.67 ± 0.76	1.38 ± 0.09
	7.74 ± 0.71	1.49 ± 0.13

Fig. 2 shows a typical set of results obtained from three runs for a given turbine configuration. In this case, the control system was set to maintain a fixed angular velocity of 70RPM or 1.17Hz. All three runs show good agreement. Sound levels increase monotonously with decreasing frequency from 40dB re 1 μPa² Hz⁻¹ at 100 kHz to 70dB re 1 μPa² Hz⁻¹ at 1 kHz. All data-sets show a distinct peak at 1.5kHz. Further features of interest below 1kHz are two pronounced double peaks at 100 and 200Hz, where sound levels rise to 80-85 dB re 1 μPa² Hz⁻¹.

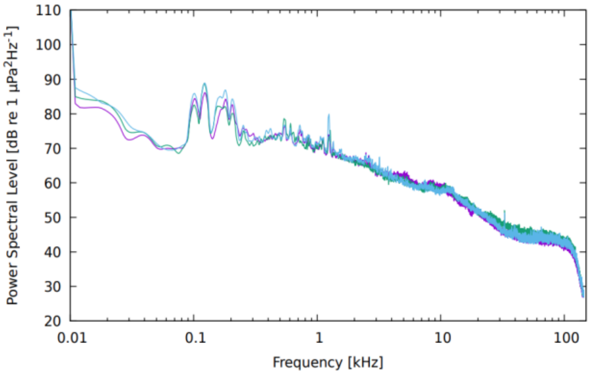

Fig. 2. Power spectral level from three runs when the two turbine controls were set to 70RPM.

The overall trends for 90RPM are very similar to the 70RPM case (Fig. 3) as described above. A distinct peak, similar in magnitude to the one observed for 70RPM at 1.5kHz appears at 700Hz for the 90RPM data. The double peaks between 90Hz and 200Hz are less pronounced for the 90RPM dataset, the highest peak of almost 90dB re 1 μPa² Hz⁻¹ observed in the 70RPM cases at 130Hz reduces to below 80dB re 1 μPa² Hz⁻¹. Between 200Hz and 600Hz sound levels are consistently higher for 90RPM than 70RPM.

Fig. 4 shows a comparison of test runs with one turbine fully stopped and the other set to run with 90RPM. A new peak, non-existent in the earlier cases at 1.15kHz is visible, reaching 87dB re 1 μPa^2 Hz^{-1}. Further peaks appear at 1.1kHz and the peaks observed for the 90RPM configuration at 1.5kHz and the 70RPM configuration at 0.7Hz are also visible with similar magnitudes. Sound levels in the 90 to 200Hz region do not show the elevated sound levels of previous cases and remain lowest of all cases with 70 dB re 1 μPa^2 Hz^{-1}.

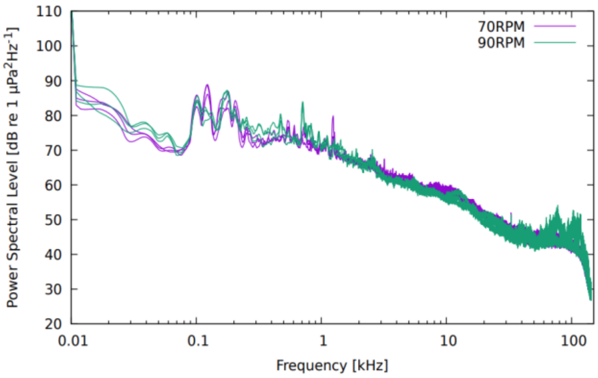

Fig. 3. Power spectral level for two sets of three runs with the turbine controls set to 70RPM or 90RPM respectively.

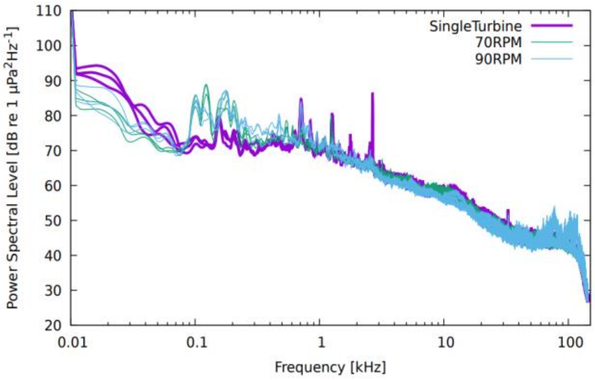

Fig. 4. Comparison of power spectral level for a single running turbine and two turbines at 70RPM and 90RPM (three sets of runs each).

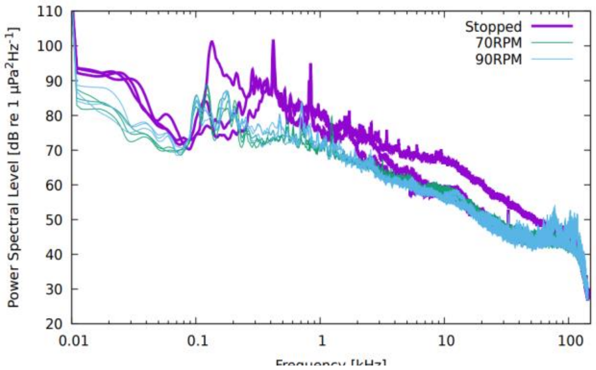

Fig. 5 Power spectra level for both turbines stopped compared to two turbines with their controls set to 70RPM and 90RPM (three sets of runs each).

Fig. 5 shows data for test runs with both turbines stopped and the 70 and 90RPM cases. Data for the braked turbines is much less consistent, one of the three runs shows 10-20dB re 1 μPa^2 Hz^{-1} higher sound levels for the entire range from 0.2 to 80kHz. All measurements with stopped turbines consistently show higher sound levels between 0.2kHz to 3kHz.

IV. DISCUSSION

Sound measurements of tidal turbines during operation are still rare and assumptions around the influence of operating states of two turbines is virtually untested against field data. Here we provide the sound emissions of two operating turbines for different configurations in a real flow environment for the first time.

In the present field test, two results were surprising, perhaps even counter intuitive: the first being that noise levels were not related to RPM and the second being that ceasing turbine operation did not lead to lower noise emissions.

The movement of the turbine blades has been considered as the main noise source by some [15]. Therefore, accelerated blade passages (i.e. higher RPM) would be expected to raise noise emissions and be related directly to the acoustic spectrum. However, our data suggests this may not always be true as neither the recorded sound levels, nor observed spectral peaks, appeared related to changes in RPM.

The cessation data failed to show any appreciable drop in noise or flattening of the spectrum and suggests the turbine structure and braked blades themselves can alter the soundscape. This may not be expected since much of the literature describes turbine noise as being predominately generated from moving parts [3-5]. Although the reason why more noise was generated over a wide bandwidth is unclear from our data, it is possible that the poorly oriented turbine blades (when braked) contributed to this. When the blades are not aligned to the flow, more vortex shedding can occur, creating vibrations and noise. It should also be noted that the velocity increased markedly from 1 to c. 1.4 m/s coinciding with this test configuration. Thrust force being proportional to the velocity squared indicates a doubling of the loading on the mooring. Braked blades will however reduce thrust, thereby changing the floating condition and tension on the mooring structure itself. The use of a single drifting hydrophone prevents any investigation into which parts of the braked system were responsible for the observations made. These variables may have contributed to the observed changes in sound levels and require further investigation.

The results suggest that noise does not simply double when an additional turbine is running, or that noise levels will drop when turbines are braked. The acoustic output is complicated, highly variable and may not be as expected. The presence of the turbine structure itself, such as the barge, is not always considered but can change the underwater soundscape for as long as the device is in commission. While in this study, the noise emitted is unlikely to impact marine animals beyond the immediate area [6], the data in this study demonstrates the complexities of the device, mooring and environment and more data is needed to better understand the soundscape around marine renewable energy devices.

ACKNOWLEDGEMENT

This work was funded by the Bryden Centre project, supported by the European Union's INTERREG VA Programme, and managed by the Special EU Programmes Body (SEUPB). We would also like to thank Ian Benson and Dr Carwyn Frost for facilitating our measurements on the barge during their testing programme.

DISCLAIMER

The views and opinions expressed in this paper do not necessarily reflect those of the European Commission or the Special EU Programmes Body (SEUPB).

REFERENCES

[1] W. J. Richardson, C. R. Greene, C. I. Malme, and D. H. Thompson, Marine mammals and noise. Academic Press, San Diego, 1995.

[2] J. Lossent, M. Lejart, T. Folegot, D. Clorennec, L. Di Iorio, and C. Gervaise, "Underwater operational noise level emitted by a tidal current turbine and its potential impact on marine fauna," *Marine Pollution Bulletin*, vol. 131, pp. 323–34, 2018. doi.org/10.1016/j. marpolbul.2018.03.024.

[3] B. Polagye, and P. Murphy, "Acoustic characterization of a hydrokinetic turbine," *in Proc. 11th Eur wave tidal energy conf.* 2015.

[4] P. Schmitt, B. Elsaesser, M. Coffin, J. Hood, and R. Starzmann, "Field testing a full-scale tidal turbine Part 3 : acoustic characteristics," *in Proc. 11th Eur wave tidal energy conf.* 2015.

[5] P. Schmitt, M. K. Pine, R. M Culloch, L. Lieber, L, and L.T. Kregting, "Noise characterization of a subsea tidal kite," *Journal of the Acoustical Society of America*, vol. 144(5), EL441-EL446, 2018. doi:10.1121/1.5080268

[6] M. K. Pine, P. Schmitt, R. M Culloch, L. Lieber, L, and L.T. Kregting, "Providing ecological context to anthropogenic subsea noise: Assessing listening space reductions of marine mammals from tidal energy devices," *Renewable and Sustainable Energy Reviews*, vol. 103, pp. 49-57, 2019. doi:10.1016/j.rser.2018.12.024

[7] B. Polagye, and C. Bassett, "Risk to marine animals from underwater noise generated by marine renewable energy devices," In A.E. Copping and L.G. Hemery (Eds.), *OES-Environmental 2020 State of the Science Report: Environmental Effects of Marine Renewable Energy Development Around the World*. Report for Ocean Energy Systems (OES), pp. 66-85, 2020. doi:10.2172/1633082

[8] K. Haikonen, J. Sundberg, and M. Leijon, "Characteristics of the operational noise from full scale wave energy converters in the Lysekil Project: Estimation of potential environmental impacts," *Energies*, vol. 6(5), pp. 2562- 2582, 2013. doi:10.3390/En6052562

[9] T. P. Lloyd, S. R. Turnock, and V. F. Humphrey, "Assessing the influence of inflow turbulence on noise and performance of a tidal turbine using large eddy simulations," *Renewable Energy*, vol. 71, pp. 742-754, 2014. doi:10.1016 /j.renene.2014.06.01

[10] J. Tougaard, "Underwater noise from a wave energy converter is unlikely to affect marine mammals," *PLoS ONE*, 10(7), 1-7, 2015. doi:10.1371/journal.pone .0132391

[11] X. Lurton. An introduction to underwater acoustics: principles and applications. New York: Springer, 2002.

[12] M. K. Pine, A. G. Jeffs, and C. A. Radford, "The cumulative effect on sound levels from multiple underwater anthropogenic sound sources in shallow coastal waters," *Journal of Applied Ecology*, vol. 51, pp. 23–30, 2014. https://doi.org/10.1111/1365-2664.12196

[13] L. Kregting, B. Elsaesser, R. Kennedy, D. Smyth, J. O'Carroll, and G. Savidge, "Do changes in current flow as a result of arrays of tidal turbines have an effect on benthic communities?," *PLoS One*, vol. 11, pp. 1–14, 2016. https://doi.org/10.1371/journal.pone. 0161279.

[14] C. Frost, et. al. In prep EWTEC 2021

[15] T. P. Lloyd, S. R. Turnock, and V. F. Humphrey, "Assessing the influence of inflow turbulence on noise and performance of a tidal turbine using large eddy simulations," *Renewable Energy*, vol. 71, pp. 742-754, 2014. https://doi.org/10.1016/j.renene.2014.06.011.