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ACOUSTIC MODELLING FOR THE ENVIRONMENTAL IMPACT ASSESSMENT OF TIDAL TURBINE ARRAYS

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Usually the first time that the operational sound from new tidal turbines can be measured is after they have been installed and are already interacting with animals in the marine environment. A modelling solution is therefore required to estimate whether marine animals will be able to hear and avoid contact with tidal turbines. An acoustic-structural interaction model is used calculate the acoustic output of tidal turbines. The cumulative sound of an array of tidal turbines and its dependence on bathymetry is calculated using a parabolic equation code. Modelled and measured sound pressure levels give information on potential upstream warning distances/times for animals which in turn helps to consider collision risk.
Keywords: Tidal turbine, porpoise, structural-acoustic model

1. Introduction

The opportunity afforded by marine energy will go a long way to help the UK and the rest of the world achieve ambitious carbon reduction targets. The leading technology in the marine sector is currently energy conversion using tidal stream turbine and Scotland has among the best tidal stream resource in the world. Tidal stream turbines are a new technology with the first industrial scale turbines due for installation in the coming years. Given the novelty of the technology there is often no opportunity to measure the noise output of turbines before they are deployed. This provided little scope by which marine regulators and consenting agencies can gauge the likely environmental impact that tidal turbine arrays will have on marine species.

Noise from tidal stream turbines that is within the audible range of marine species is associated with vibrations produced by the drive train components such as the gearbox and generator. These vibrations travel through the drive train to the rotor, nacelle walls and support structure where it interacts with the surrounding water and is released as noise. This noise is potentially harmful to marine species and could cause injury or death. The noise may also have an advantage effect in so far that it warns marine species of the presence of a turbine and thus provides a warning that allows the animal to avoid collision with the moving part of the turbine. This paper focuses on predicting the range at which marine mammals can hear a tidal turbine array and collision risk.

Xi Engineering Consultants have used the methodology discussed below to predict operational noise for proposed commercial tidal turbine arrays that have been submitted to regulatory bodies in a number of countries. Due to commercial sensitivity of this previous work, a fictional demonstration array on the west coast of Scotland has been modelled here consisting of six generic single rotor 1 MW turbines. Results of this model can be used predict the noise impact on marine species; here the harbour porpoise is used as an example.

2. Technical Background

Source of noise in tidal stream turbines

Noise for tidal turbines has two principal sources: mechanical noise associated with the rotating machinery in the drive train and noise associated with hydrodynamic effects as the blades pass through the water such as cavitation. Particular effort in the design of tidal turbines is made to avoid hydrodynamic noise caused by cavitation which is very destructive to the blades. The great majority of noise in the marine environment due to tidal turbines is therefore related to mechanical vibration in the drive train.

Mechanical vibration in the drive trains of tidal turbines are created by imbalances of the rotating components, the teeth in the gearbox coming into contact with each other (referred to as gear meshing), and electro-magnetic (E-M) interaction between the spinning poles and stationary stators in the generator. Each of these vibration sources occurs in discrete frequency bands related to the rotation speed of each component: the vibrations therefore tend to be tonal (as opposed to broad band). Rotational imbalances tend to occur at very low frequencies (< 50 Hz), while gear meshing and E-M interactions tend to occur at low to moderate frequency (50 Hz to 2 kHz). Other mechanical vibrations produced by tidal turbines during normal operation tend to be of a temporal nature with durations of seconds to tens of seconds. These can include the pumping of hydraulic fluid and cooling systems.

3. Methodology

The near-field sound field produced by a single generic 1 MW tidal turbine was calculated in three-dimension using finite element methods. The results from the near-field model were used to populate a far-field model which considers the effects of bathymetry and sea bed to calculate the cumulative sound generated by an array of six 1 MW tidal turbines. The fictional tidal turbine array was placed between Colonsay and Jura on west coast of Scotland (Fig. 1).

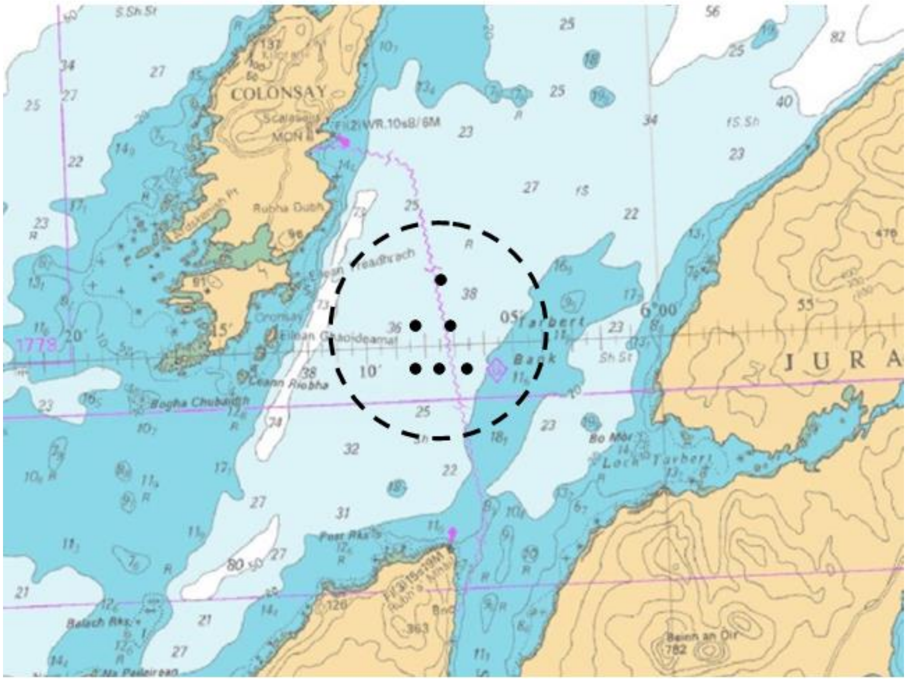

Figure 1: Position of the fictional tidal turbine array between Colonsay and Jura on the west coast of Scotland.

3.1 Near-field model

The near-field sound field within 25 m of the generic 1MW tidal devices was calculated with a fully coupled structural-acoustic interaction model using the commercially available, finite element package, COMSOL Multiphysics. Calculations were performed in the frequency domain at 16, 20, 25, 32, 40, 50, 63 Hz then across a band of 70 to 2000 Hz with the frequency discretised into 10 Hz steps.

The structural component of the model consists of the generic turbine and has a single rotor with three blades each with 9.5 m long and a hub height of 15 m (Fig. 2). The turbine has a conventional horizontal axis drivetrain consisting of low-speed shaft, three-stage step up gearbox, high speed shaft and generator. The structural component of the model is surrounded by a cylindrical acoustic domain with a radius of 50 m and a height of 40 m, and represents the external water.

The structural component of the model is excited by applying forces to the cylinders that represent the drive train. The magnitude of the forces is varied as a function of frequency such that it occurs in discrete frequency bands related to gear meshing and its harmonics. This is done using peaks of the force in the frequency domain $F_{(f)}$ that take the form of summed normal distributions according to:

$$F_{(f)} = F_{mesh} \sum_{n=1}^{15} \frac{e^{\left(\frac{-f-f_{mesh}}{n}\right)}}{2\sigma^2} \frac{1}{n}, \qquad \text{(Eq 1)}$$

where F_{mesh} is the force representing the gear meshing at each step-up stage, f is the gear meshing frequency of each gear stage, σ is a shape term that defines the frequency range over which the gear meshing is effective and f_{mesh} is the gear meshing frequency. The meshing frequencies f_{mesh} were taken to be 25 Hz, 150 Hz and 700 Hz, relating to the first, second and third step-up stages respectively. The values for the parameters of F_{mesh} and σ were based on measured values of 1 MW drive trains in similar wind turbines (Carruthers and Marmo, 2001). The model is solved producing a three-dimensional sound field that is directional (Fig. 3) and the directionality is dependent of frequency.

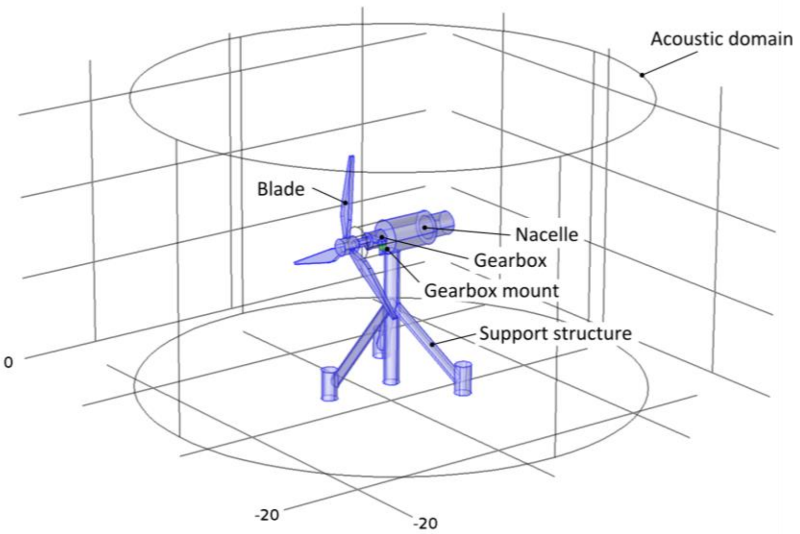

Figure 2: Geometry of the 1 MW tidal turbine used in the near-field model

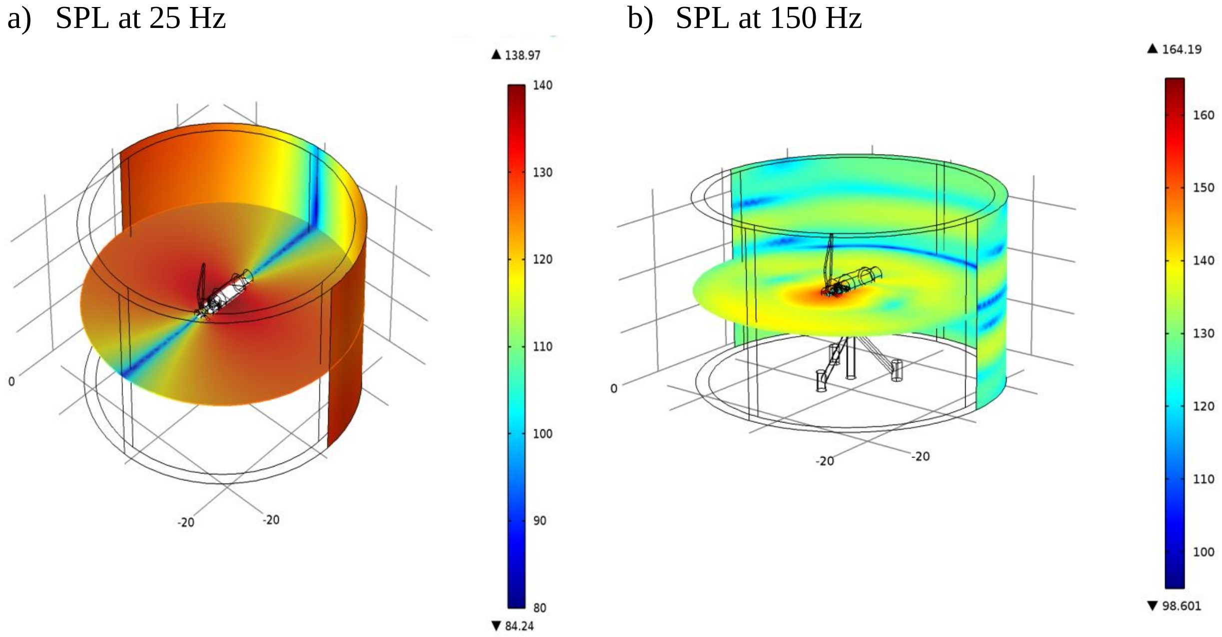

Figure 3: Directionality of the modelled near-field sound field. a) SPL modelled at 25 Hz due to vibration related to gear meshing in the first step-up stage. b) SPL modelled at 150 Hz due to vibration related to gear meshing in the second step-up stage.

3.2 Far-field model

The sound field up to 10 km from the fictional tidal turbine array was modelled using a parabolic equation code model (AcTUP, produced by CMST at Curtin University). Coherent transmission loss was modelled through two dimensional vertical sections radiating from the position of each tidal turbine. The seabed geometry of each radial section was based on the bathymetric maps (Fig. 1). To simplify the model it was assumed that there was no surface roughness and that the speed of sound profile was linear.

The SPL for each radial section of the near-field model was converted to a point source by back-modelling the transmission loss to the centre of the near-field model space. The sound level of each vertical section was determined by subtracting the far-field transmission loss fields from the near-field point source levels for each angular direction. The turbines are assumed to be oriented parallel to the tidal current that run ~245° from true north. In this way directional dependence of sound level from the near-field models maps in to the far-field acoustic model. Thirty-six vertical sections were modelled radially around each of the proposed turbine sites.

The 3-dimensional sound fields for each turbine in an array were summed incoherently using the computer package Matlab, to produce a 3-dimension sound field measuring 10 km × 10 km × 150 m in one-third octave frequency bands between 16 and 2000 Hz for each of the array layouts. The resultant sound fields tend to be directional due to a combination of the directionality of the source and bathymetric effects (Figs. 4 & 5). Peaks in the sound field are related to gear-meshing in the first step-up stage (25 Hz one-third octave band) and the second step-up stage (160 Hz one-third octave band) (Fig. 5).

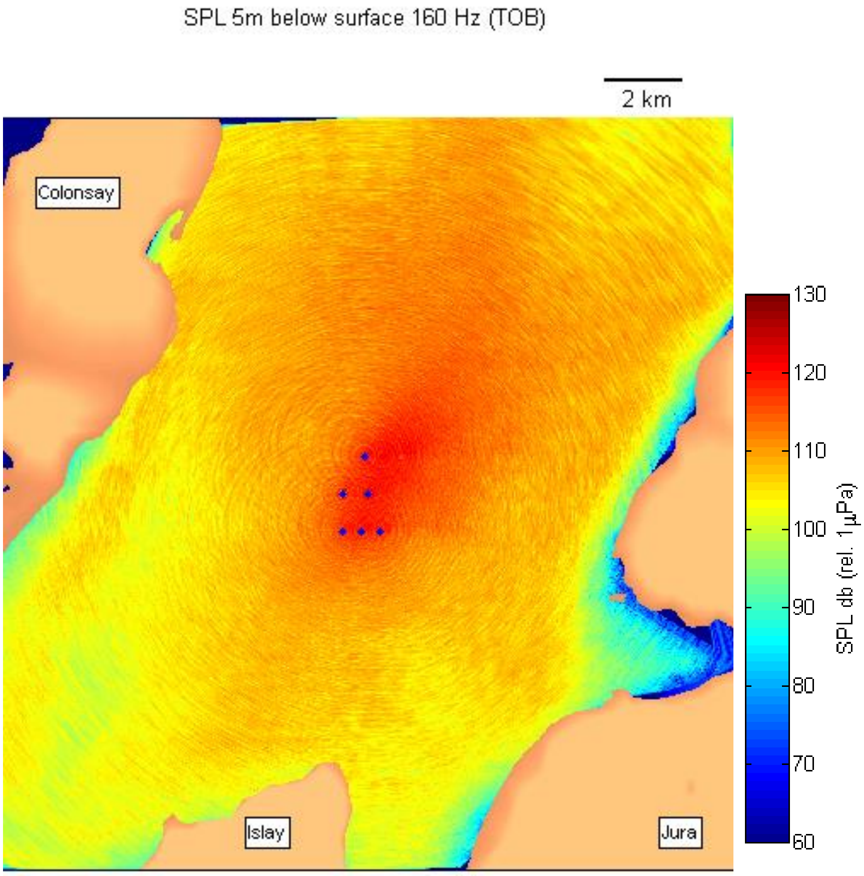

Figure 4: The cumulative sound pressure level in the 160 Hz one-third octave band from six operational tidal turbines. This one-third octave band contains sound related to gear meshing of the second step-up stage (150 Hz) in the gearbox.

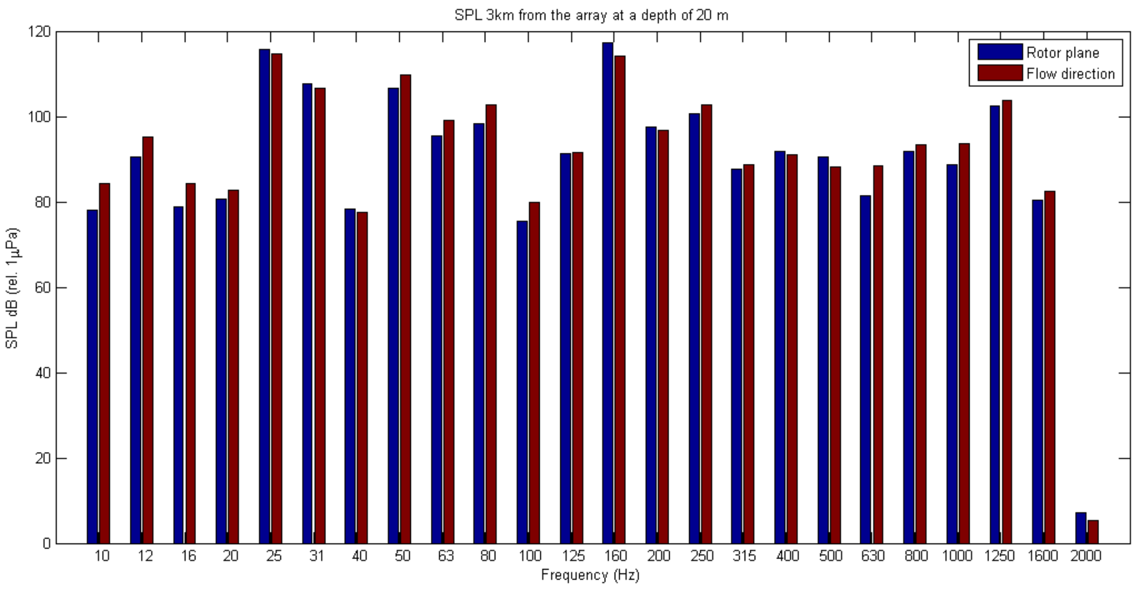

Figure 5: Cumulative sound pressure level 3 km from the tidal turbine array down-stream (flow direction) and parallel to the rotor plane.

4. Marine mammal collision risk

The three dimensional and frequency dependent nature of the modelled sound field can be used to determine the range at which it is possible for a marine mammal to detect the presence of operational turbines and thereby avoid impact. The detection range is determine by comparing the modelled sound level to the measured threshold of hearing of the target species. Consider a habour porpoise, which has sensitive hearing at high frequency (> 1 kHz), but relative poor sensitivity at low frequency (Fig. 6). The harbour porpoise would not detect low frequency sound produced by the gear-meshing of the first and second step-up stages. However, it would be able to detect higher frequency sound related to the third step-up stage and harmonics of the second step-up stage resulting in the ability to detect the array up to 6.5 km from the array in the 800 Hz one-third octave band (Fig. 7)

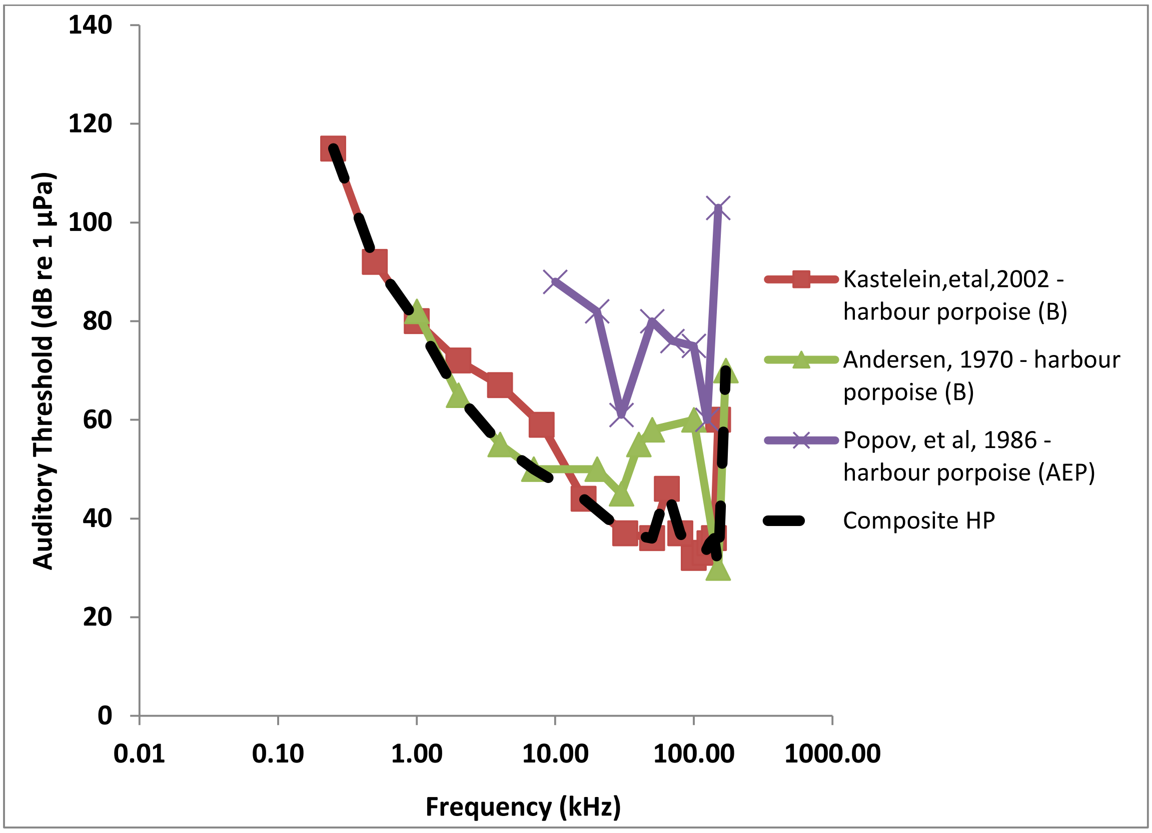

Figure 6: Audiogram for harbour porpoise

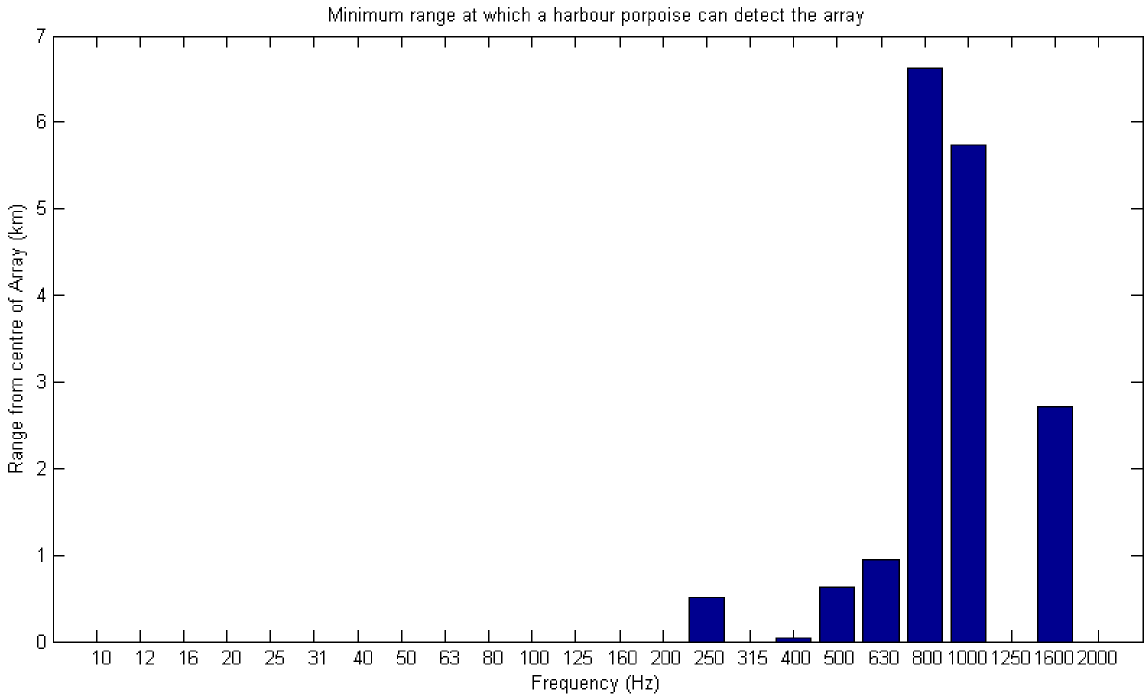

Figure 7: Range at which a harbour porpoise could detect the operational tidal turbine array based on the threshold of hearing shown in Fig. 6 and the modelled sound field.

5. Conclusion

A modelling approach is used to predicted the cumulative sound level produced by the operation of six 1 MW tidal turbines at a fictional array between Colonsay and Jura. The sound pressure level is frequency dependent due to the discrete nature of mechanical vibrations in the drive train. The sound field also varies in level with angular position due to the directional nature of the noise source and bathymetric effects. The modelled sound field can be compared to the hearing thresholds of marine mammals. The hearing sensitivity of a harbour porpoise was used as an example to show that it would be possible for a porpoise to detect the presence of the tidal array at a distance of 6.5 km in the 800 Hz one-third octave band and thereby avoid collision. These types of analyses can be used to inform marine regulators on the affect of installing tidal energy devices on marine species.

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