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T1.7.3 Test Procedure Report 2 IEC/TS62600-200 Feedback and Recommendations for Floating TEC Incident Resource Measurement for Power Performance Assessment

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Document History

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0.2	20/09/2022	Addition of Test Procedure Guidance	Craig Dibb	Penny Jeffcoate	-
0.3	05/10/2022	Final revisions	Craig Dibb	Penny Jeffcoate	Caroline Lourie

Disclaimer

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Executive Summary

This report is part of the deliverable T1.7.3 – Accredited turbine performance test procedures - under the Interreg Channel Manche – TIGER project.

This report assesses any potential areas of improvement in the IEC/TS 62600-200: Electricity producing tidal energy converters – Power performance assessment technical specification when applied specifically to floating TEC's, with a specific focus on the incident resource measurement.

The output outlines a proposed guidance and recommendations for measuring the incident resource when assessing the performance of a floating TEC based on EMEC's experience using the technical specification in practise.

Abbreviations

Acronym	Meaning
AEP	Annual Energy Production
ADCP	Acoustic Doppler Current Profiler
ADV	Acoustic Doppler Velocimeter
AHRS	Attitude and Heading Reference System
BSI	British Standards Institute
ECM	Electromagnetic Current Meter
EMEC	European Marine Energy Centre
ENU	East-North-Up (Coordinates)
ERDF	European Regional Development Fund
FCE	France (Channel Manche) England
GPS	Global Positioning System
HAT	Highest Astronomical Tide
IEC	International Electrotechnical Commission
ISO	International Organisation of Standardisation
JS	Joint Secretariat
LAT	Lowest Astronomical Tide
MHW	Mean High Water
MLW	Mean Low Water
PPA	Power Performance Assessment
PSG	Project Steering Group
SAG	Stakeholder Steering Group
TIGER	Tidal Stream Industry Energiser
TEC	Tidal Energy Converter
TC	Technical Committee
TS	Technical Specification
TSE	Tidal Stream Energy
UKAS	United Kingdom Accreditation Service

1 Introduction

The purpose of this report is to provide suggestions for guidance for how to conduct incident resource measurement during the power performance assessment of a floating tidal energy converter (TEC).

The first part of this report summarises the current requirements and guidance from the IEC/TS 62600-200: Electricity producing tidal energy converters – Power performance assessment technical specification (IEC, 2013). The second section makes suggested recommendations based on EMEC's own experience in using the specification and proposes possible procedures for floating tidal device testing.

The aim is then for this document to act as feedback to the IEC/TS 62600-200 maintenance team so that the comments can be considered as the second edition is developed.

This activity falls under the scope of the Interreg Channel Manche – TIGER project, intended to develop a go-to pan-European energy supply chain resource in the channel region.

1.1 Tidal PPA Technical Specification when Applied to Floating TEC's

The current technical specification (IEC/TS 62600-200: Electricity producing tidal energy converters – Power performance assessment technical specification) has well defined requirements for carrying out a power performance assessment. The standard plays an important role in building investor confidence in the sector and helping to accelerate commercialisation. The power performance assessment relies on the measurement of the incident resource. Upstream seabed mounted ADCP's are viewed as the most dependable measurement method. It is, however, an expensive and operationally complex method for developers to take on, especially for developers of floating TEC's who are aiming to reduce seabed operations (C.Frost, 2021).

At the time of publication of the technical specification (2013), the industry was generally dominated by horizontal-axis, bed-mounted turbine devices. Over the ten years since its publication, the industry has advanced and there are many other types of devices being developed. This variety is demonstrated amongst the four developers under the TIGER project where there is a range in concept types, as can be seen in Table 1.

Developer	TEC type
HydroQuest	Seabed mounted, vertical axis
Orbital Marine Power	Floating, horizontal axis
Minesto	Kite
QED Naval	Seabed mounted, horizontal axis

Table 1 - Device types of developers in the TIGER project

In recent years, EMEC has observed a trend towards floating devices amongst the developers coming to test in Orkney. Orbital Marine Power's O2 and Magallanes' ATIR are both examples of horizontal-axis floating devices which are currently deployed at EMEC's Fall of Warness tidal test site. That is not to say that the industry in converging on any particular design or diverging away from seabed mounted horizontal axis turbines, but it is clear that there are plenty of developers developing floating TEC's. It is EMEC's experience, that the IEC's requirements and guidance for measuring the incident resource measurement for floating TEC's is often not practical (IEC, 2013).

This report reviews the latest technical specification critiquing its relevance for floating horizontal and vertical-axis TEC's. Other TEC types are considered in the 3rd report under this deliverable (T1.7.3).

2 Incident Resource Measurement (Section 8.9 in IEC/TS62600-200)

The requirements for incidence resource measurement positioning are defined in section 8.9.1 of the IEC/TS 62600-200 and state:

"*The positioning of the measuring instruments should be such that they capture the ambient current behaviour without modification due to the proximity of the TEC, but sufficiently close to the TEC to be representative of the local current regime*."

Ultimately, the resulting power curve needs to demonstrate how effective the device is at converting the kinetic energy of the tidal stream into electricity in a way which allows comparability between sites and devices. In certain test sites, this may be impractical to completely achieve due to natural variance in the resource across the test berth, even in the case of a fixed TEC position.

The specification defines two options for the measurement positioning: orientation A – In-line and orientation B – Adjacent, as can be seen in Appendix A:, which in the general case works well for seabed-mounted ADCP's.

The specification then goes on to provide the following guidance surrounding floating TEC's (IEC, 2013):

- "*a current profiler mounted on the TEC itself that complies with orientations A or B;*
- *a bottom mounted current profiler on both ebb and flood tides positioned in such a way that the footprint (the area described by the intersection of the energy extraction plane and the principal axis of energy capture) does not exceed the dimensions; (as detailed in Figure 5-1 of this report*).
- *if none of these deployment orientations are achievable, an array of bottom mounted current profilers may be used, and a correction methodology developed and justified, such that the ambient current behaviour without modification due to the proximity of the TEC is measured. One method of justifying a methodology would be to perform a site calibration*."

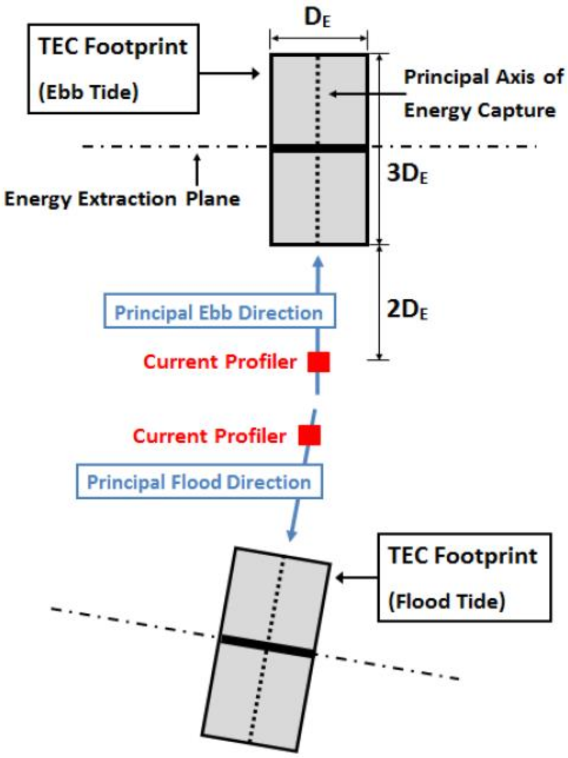

Figure 2-1 - Orientation for floating TEC current profiler deployment (plan view)

In EMEC's experience, these requirements are not always practical for floating devices.

For the first option, it is not always achievable to mount an ADCP on the TEC and achieve the compliance with the required orientations in a way that has 10 bins over the capture area (as per section 7.2 (IEC, 2013)) or adequate distance upstream from the rotor capture plane. The use of the word 'footprint' here is not consistent with how it is used elsewhere in the document, as outlined in the MET-Certified document (EMEC, 2018). Where it is achievable, further guidance on installing instruments and managing the measurement design is still needed.

For the second option, there are practical issues with the deploying upstream and downstream current profilers, including the presence of mooring lines. Additionally, there are considerations for the TEC movement relative to static bed mounted ADCP's and the resultant incoming flow angle and thus velocity to the rotor plane.

In the third instance, ideally a site calibration would be performed; however, doing this with an array of ADCP's may be financially unachievable for the developer and there is no further guidance on how to perform the site calibration within the -200 TS (IEC, 2013). Site calibration requirements and guidance for wind turbines can be found of the IEC 61400-12 (IEC, 2022) (IEC, 2012).

2.1 Considerations for Incident Resource Measurement for Floating TEC's

The challenges can be categorised into the following as to why the current guidance, without any deviation or modification, is not appropriate for floating TEC's:

- Site specific:
    - Test site resource variation
- Instrumentation limitations:
    - Tilt
    - Beam spread
    - Side-lobe contamination
    - Interference between ADCP's
- TEC specific:
    - Bed mounted ADCP's
        - Equivalent diameter
        - Local flow field effects of TEC
        - Obstructions
        - TEC motion
    - TEC mounted ADCP's
        - Local flow field effects of TEC
        - Calibration
        - Tilted ADCP's
        - Spinning
- Additional Considerations
    - Cost
    - TEC Size
    - Data complexity

2.1.1 Site Specific Aspects

Sites suitable for Tidal Stream Energy are typically high energy and turbulent. Some variation across the berth is expected. At sites where this variation may be large, most likely due to the bathymetry, the room for error in the current profiler positioning, such that it is representative of the global flow at the TEC's position whilst avoiding the TEC's local flow impacts, becomes narrower. If the device has a large equivalent diameter (D_E), the ADCP will be required to be further away, understandably to account for the increased local effect of the turbine. However, in a site with high variance in current, that may result in the resource measured being different to that experienced at the TEC location which in turn can have significant impacts on the power curve.

It is at the site characterisation phase of the testing (captured in section 5 of the TS (IEC, 2013)), or when undergoing a resource assessment, that measurements can be taken to better understand this variation. In sections 5.2 and 5.4 for Bathymetry and TEC test site constraints (IEC, 2013), respectively, items such as non-uniform bathymetry and the blockage affect are considered, however there is no requirement to quantify the variance in resource between the measurement locations and the TEC position unless a significant variation in bathymetry is noted. In the case of larger floating TEC's, where the margin for error may be smaller when attempting to measure the global flow field representative of the TEC position.

2.1.2 Instrumentation Limitations

Multi-beam current profilers are currently required to measure the incident resource at sufficient accuracy. As the power performance is only a small part of the testing that a developer may carry out on a TEC prototype, finding a solution which is both affordable for developers and practical to the point where developers could implement the method into design and use the data collection for other purposes, such as control or condition monitoring, will be most beneficial for helping to progress the sector forwards.

2.1.2.1 Tilt

Nowadays, modern ADCP's are capable of measuring in any orientation* and can output real-time bin-mapped data. To enable this, the instrument needs to be measuring in East-North-Up (ENU) coordinates which uses the instruments internal compass. Errors can still be observed due to the motion of the instruments' platform, or any acceleration other than gravity. This in turn results in miscalculations in the cell location within the water column and causes vertical velocity smearing in the data. Using Attitude and Heading Reference System (AHRS) enabled ADCP's prevents these errors in the tilt and heading sensors (Nortek, 2022).

*Modern ADCP's can measure in a full three dimensions however, gimbal lock will occur if the main horizontal (X axis) of the ADCP is aligned with the global vertical (Z axis). This impacts the heading reading.

2.1.2.2 Beam Spread

Current profiles use slanted beams and so the distance between the beams increases with distance. For seabed mounted ADCP's, this means that the beams will be at their greatest separation in the upper part of the water column, at the capture area of a floating TEC. The current profilers assume horizontal homogeneity between the beams and so a higher uncertainty can be associated with the current measurements at a greater range from the ADCP unit. How to calculate this uncertainty is not well defined in the specification.

For example, a bottom mounted ADCP with a beam angle of 25 degrees will have a beam spread of ~30 metres at hub height depth of 30 metres. This is the horizontal distance from the centre of one bin to the centre of the opposite and it does not consider width of the individual the beams. Nevertheless, for a device with an equivalent diameter less than 28m, the area that the ADCP beams are measuring over is larger than the maximum area that orientation B allows (1D_E squared, as illustrated in Figure 2-2), or orientation A allows in terms of box width. A device with an equivalent diameter smaller than the beam spread could also exceed the 1-2D_E specification. This is a minor point in terms of impact on the quality of the test, however, it would technically be a deviation.

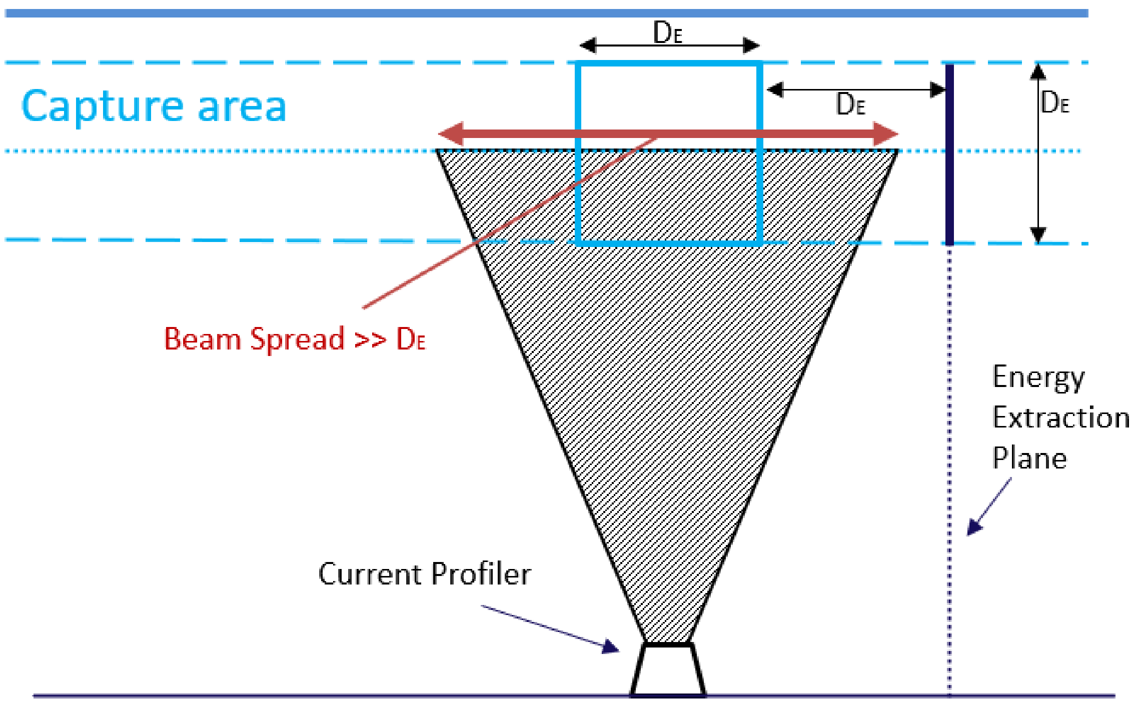

Figure 2-2 - Illustration of beam spread being larger than equivalent diameter

2.1.2.3 Sidelobe Contamination

Acoustic leakage to the side of the main beam, or lobe, in what is known as the sidelobes can create interference when reflected from a strong scatterer. The sidelobes have little effect over most of the range due the acoustic power of the sidelobes being weak compared with the main lobe. The surface, however, is a strong reflector and reflections of the sidelobe signal from the surface contaminates the upper part of the water column with interference when using a seabed mounted profiler. This affects approximately the top 10% of the water column.

As the capture area of a floating TEC is typically near to the surface, upward facing ADCP's can struggle to capture the entire capture area of the turbine, which means failing to satisfy point 2 of section 7.2 of the TS (IEC, 2013). For example, an ADCP in 50 metres of water depth, will need to disregard the top 5 metres of the column. For a TEC with a capture area height of 10 metres (rotor diameter) and a hub height of 43 metres (hub depth 7 metres), this will affect the top 3 metres (30%) of the capture area. This is illustrated in Figure 2-3.

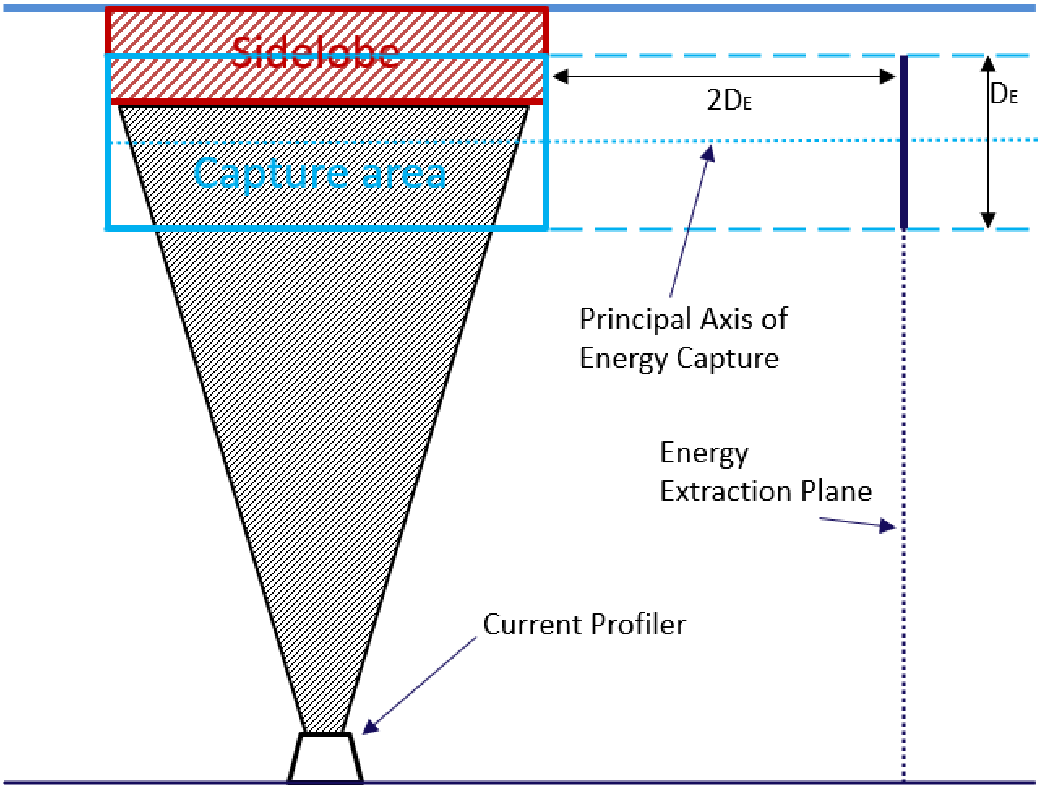

Figure 2-3 - Illustration of Sidelobe impact on floating TEC capture area

Additionally, mooring systems used for floating devices can affect the sidelobe contamination, since chain and cables are strong reflectors. Sidelobe contamination will also need to be considered on horizontally orientated ADCP's, caused by both the surface and seabed.

2.1.2.4 Interference between ADCP's

An obvious limitation with the instruments is that interference can occur between devices. To avoid this, a distance of 3 times the beam range is recommended, e.g., with a device range of 50 metres, the units would need to be at least 150 metres apart. This makes designing a site calibration using an array or a mixture of TEC-mounted and seabed-mounted ADCP's more complex.

2.1.3 TEC Specific Aspects

At present there are a range of different types of floating TEC's of different geometries, turbine designs and mooring systems. The limitations will be different for different types of devices, but this considers horizontal or vertical axis devices on a floating structure, moored to the seabed with multiple mooring lines of rope or chain, similar to Orbital's O2, Sustainable Marine's PLAT-I, or Magallanes device.

2.1.3.1 Bed Mounted ADCP's

- **Equivalent Diameter -** The specification requirements for ADCP positioning are based on the equivalent diameter (D_E) of the TEC, which can result in the specified zones being far from the TEC, especially for multi rotor devices. There is also ambiguity for multi-rotor devices mounted fore-aft, since the standard only considers the 2D cross sectional area of the incident flow; this is adequate for defining the incident flow but the D_E calculation for upstream/downstream devices should be stated.

- **Local Flow Field due to TEC Presence -** Each TEC will have device specific local flow fields when in a tidal stream. To measure the incident resource measurement as global flow representative of the TEC's position, this local flow field needs to be considered and the measurement methodology designed to either avoid this or account for it. This means that, without any convergence or standardisation in the floating TEC's being developed today, each case may require a different methodology.

- **Obstructions** - The mooring spread and device electrical cable is likely to create a deployment obstruction. The typical four-point mooring system usually makes orientation A impractical, but in the very best case will place limits on the mooring spread of the seabed mounted ADCP. Aside from the obvious seabed instrument deployment challenge due to the mooring lines, there is also the possible cause of beam interference. Orientation B usually avoids any mooring lines, however there may be cases where orientation B cannot be completely used if the electrical cable is in close proximity.

- **TEC Motion** - A moored device will also show some degree of compliance which can create alignment issues between the flood and ebb. As raised in the MET-Certified feedback (IEC, 2013) to the IEC on the TS62600-200, orientation B does not allow much flexibility for inaccuracy in instrumentation deployment due to its small tolerance of only $1D_E$. There may not be any overlap of the adjacent boxes for each tide if the principal ebb and flood directions are not exactly opposite, as illustrated in Figure 5-5 of Appendix B:. Additionally, if there is significant slack in the mooring system due to a large tidal range then the low water flood and ebb positions can be significantly separated, and thus outside the tolerances of the specification.

The motion of the TEC (heave, surge, sway, pitch, roll, yaw) will also affect where the ADCP is relative to the rotor plane. An eddy could cause yaw and sway of the TEC about the mooring such that flow is significantly misaligned from the principal axis of capture. This misalignment will could significantly impact results for performance measurement. Correcting is not currently covered in the TS, but it could be an extremely complicated post-processing step.

Additionally, a multi-rotor system may have shear across the width of the TEC device, thus the incoming flow for each rotor may be different.

The hub height of the device will not be constant when measured as a depth value. For seabed current profilers, this adds an extra processing step to ensure that that the bin mapping for the capture area is maintained throughout a tidal cycle. There is no guidance or requirements on this in the specification currently.

2.1.3.2 TEC Mounted ADCP's

- **Local Flow Field due to TEC Presence -** Ensuring the instrument is measuring across the capture area at a point that is upstream enough to be free from the local pressure field of the TEC can be challenging. The instrument will need a high enough range to achieve this but will be limited by the mooring configuration, the TEC geometry and acceptable tilt angles of the instrument.

  The boundary layer of the device will need to be considered for a hull mounted instrument. If the instrument is flush, or doesn't protrude beyond the boundary layer, low quality data will likely be measured due to interference from turbulence. This can be mitigated by mounting the instrument such that it is beyond the boundary layer.

- **Calibration -** For post-processing/bin-mapping the instruments need to be measuring in ENU which uses the instrument's internal compass. The internal compass is likely to suffer from interference due to the being mounted on the TEC. It is therefore important that that the sensor compass is properly calibrated. Most modern instruments can accept an external compass which would be a better method (Nortek, 2022).

  The floating TEC is likely to undergo motion due to wave and tide action which may create bin mapping issues which result in velocity smearing. This can be mitigated by using an Attitude and Heading Reference System (AHRS) on the instrument.

- **Tilting ADCP -** Depending on the TEC geometry, the ADCP will likely need to be tilted in order to comply with orientation A or B, if mounted on the TEC hull. Any tilt will need some form of bin mapping. At more extreme tilt angles, it may become impossible for the instrument to achieve a vertical profile that is compliant with the requirements of a minimum number of 10 bins and a maximum size of 1 meter across the capture area (IEC, 2013).

- **Hub Mounted ADCP -** Hub mounted ADCP's are a possible solution and will allow the incoming velocity at hub height to be measured. A vertical profile across the capture area, however, will not be possible using them. This will mean that they are only appropriate for situations where there is negligible vertical shear profile across the capture area. The geometry of the TEC, and ultimately the hub height will put limits on the measurement area, however the local flow field of the TEC should be observable in the data and then the measurement area can be justified from that. Sidelobe contamination due to reflections from the seabed and surface, mooring and cable obstructions, and the TEC geometry will all need to be considered.

  A hub mounted ADCP will likely be spinning with the turbine in a conventional horizontal axis design. This will mean that the beams are stationary relative to the blades but in motion relative to the capture area. This will require complex bin mapping to process the data in the required way as the TS currently states. Any errors induced by the device rotation will need to be documented and incorporated into the uncertainty.

  If the vertical shear profile has been shown to have negligible variance, then the need for a multi-beam ADCP may not be necessary and a single point velocity meter, such as an Acoustic Doppler Velocimeter (ADV) or Electromagnetic Current Meter (ECM) could suffice.

2.2 Additional Considerations

ADCP's were recommended in the specifications at a time when most devices were large, both in dimension and in power output; however, the industry now has more variety in device types and the following considerations are putting constraints on smaller TEC's.

2.2.1 Cost

A large power output device, e.g. 2MW, is inherently expensive and thus a ~£40k ADCP unit is relatively insignificant in terms of instrumentation costs. A smaller, cheaper TEC, e.g. 70kW, is substantially cheaper and smaller scale operation and so a high specification, costly instrument such as an ADCP is a large proportion of project budget.

Also, when considering bed-mounted devices, marine operations to deploy and recover bed mounted ADCP's can be appropriate relative to project size (large project, well developed area, readily available vessels, low steaming/mobilisation times and costs), but not for smaller projects.

2.2.2 TEC Size

Currently in the sector large diameter rotor sizes are in the range of 18-20 metres diameter and so mounting a hub ADCP is possible, but smaller rotors with a hub size of ~0.5 metre cannot accommodate an ADCP.

Conversely, a smaller rotor with a smaller D_E could have an ADCP mounted on the structure and have sufficient upstream distance (2 to $5D_E$) whereas a large rotor device might not.

2.2.3 Data Complexity

Post-processing ADCP's is complex process. Many ADCP's use a velocity measurement onboard for control and other operational and development orientated activities which are unrelated to the independent assessment of power performance. Using an ADCP for this application could be too complex for the processing systems. Using simpler units, e.g. point meters or logs, could be a more cost and data-efficient method for many developers, albeit with a calibration campaign against more scientific instruments to prove accuracy.

2.3 Summary of Challenges

There are a range of challenges in measuring the incident resource for a floating TEC, and due to the variety of floating TEC concepts, finding a 'one size fits all' solution to a methodology will not be possible. Even as the sector standardises, it is likely there will always be some exceptions to the 'norm'. There is, however, a need to define some guidance on how the test methodology for resource measurement should be designed so that repeatable and comparable tests can be conducted. Furthermore, to design a methodology that can easily be incorporated into the developer's standard, non-PPA testing would be most cost beneficial for the sector.

Ultimately, one of the following needs to be achieved as a minimum:

- A vertical profile of 10 bins over the capture area at 2 to $5D_E$ upstream of the extraction plane, or $1\text{-}2D_E$ perpendicular to the principal axis of Energy capture, as per orientations A or B, respectively (IEC, 2013)
- Incoming velocity at hub height
- A sensitivity study showing why an alternative set-up is sufficient

There are of course quite a few options for measuring the resource from onboard a TEC, which can be narrowed down to 3 options, each of which comes with its own drawbacks:

- **ADCP's mounted in the TEC hull facing down** - This requires a TEC geometry that allows the profiler area to fulfil the requirements of orientation A or B. If that is possible, then the current guidance is mostly sufficient however, additional requirements for verifying that there is no local flow field impact on the measuring volume due to the TEC's presence should be required.

- **ADCP's mounted in the TEC hull tilted forwards** – This is also dependent on the TEC geometry; however, it could be a solution to achieving the required orientations with a TEC geometry that does not allow the above point to be possible. Constraints will need to be defined on the maximum tilt allowable to ensure that there is suitable fidelity, or number of bins, across the capture area. It may be that a tilted ADCP is more desirable for other data gathering campaigns as part of the TEC development. If this set-up is the most preferable but achieving the orientations is not possible, conducting a sensitivity study of the TEC's local flow field should be required to justify measuring the capture area at a distance less than $2D_E$.

- **Mounted in the turbine hub to capture incoming, hub height current -** This cannot satisfy the requirement of a vertical profile (Section 7.2, TS (IEC, 2013)), however will enable incoming hub height velocities to be measured and will capture the limit of the effect or rotor presence upstream.

- **Using an alternative method –** For example, a single point device could be used, though a full sensitivity study must be conducted to prove its suitability.

3 Proposed Procedure Guidance

Where possible, the IEC required orientations and measurement zones should be used. Where possible a vertical profile made up of a minimum number of bins equal to the value of the equivalent diameter (i.e. 5 bins minimum for an equivalent diameter of 5m) with a 1 metre maximum height across the TEC capture area. Where that is not possible, justification that the employed alternative is satisfactory will be needed. The following guidance attempts to cover the likely exceptions and minimum required justifications for alternative solutions.

There two primary options here: Seabed-mounted and TEC-mounted current profilers

3.1 Seabed-mounted Current Profilers

As already discussed in depth, the requirements for using seabed mounted ADCP's when assessing power performance is well established for seabed-mounted instruments, and it is also a reliable method for seabed mounted ADCP's. In the case of floating TEC's, it is not always the best method, however, it may be that it is the only method available. The following guidance is for seabed-mounted current profilers for floating TEC's.

3.1.1 Site Variation

If the TEC has a large equivalent diameter the required measurement zones will be far from the TEC location and the variation in resource between the two positions may be significant. Currently the TS (IEC, 2013) only requires investigation into that variance if there is extreme bathymetry or the possibility of blockage due to the device size. Despite that, it may not be in the developer's interest to measure at those extreme locations as the power curve may not be representative. Depending on the test site, a device with an equivalent diameter of greater than 20 metre is likely to experience resource variation between its position and the measurement location. Undergoing activities to understand this will likely be expensive and time consuming and may only confirm what is already expected. It would be most cost effective to switch the TEC-mounted current profilers at this point (See section 3.2). If that is not possible, then a solution may be to define a new measurement location, but if that location is not compliant with the TS (IEC, 2013), evidence will be needed to be collected to confirm that the new alternatives are valid.

This could be achieved by:

- Comparison of current profiler datasets of the proposed location and the TEC location before the TEC is deployed. This could become onerous if evidence is needed to justify that the TEC flow field is not influencing the chosen location, which would require both pre- and post-deployment datasets
- Numerical modelling of the site with a single reference dataset to validate the model.

Both options would be expensive activities to undertake. Where possible, activities designed to validate test methodologies should be designed to reduce cost as much as possible.

3.1.2 Orientation for Seabed mounted Current Profilers for Floating TEC's

Beam spread must be considered, irrespective of the chosen orientation and care needs to be taken to avoid interference from hard reflectors, such as mooring lines, the surface, or the TEC body.

If orientation B (see Appendix A:) is chosen, Figure 3-1, modifications to the dimensional requirements should be made to account for the beam spread, as illustrated in Figure 3-2. As described by the specification (IEC, 2013), the minimum distance from the measurement volume to the extraction plane lateral extent must always be greater than $1D_E$.

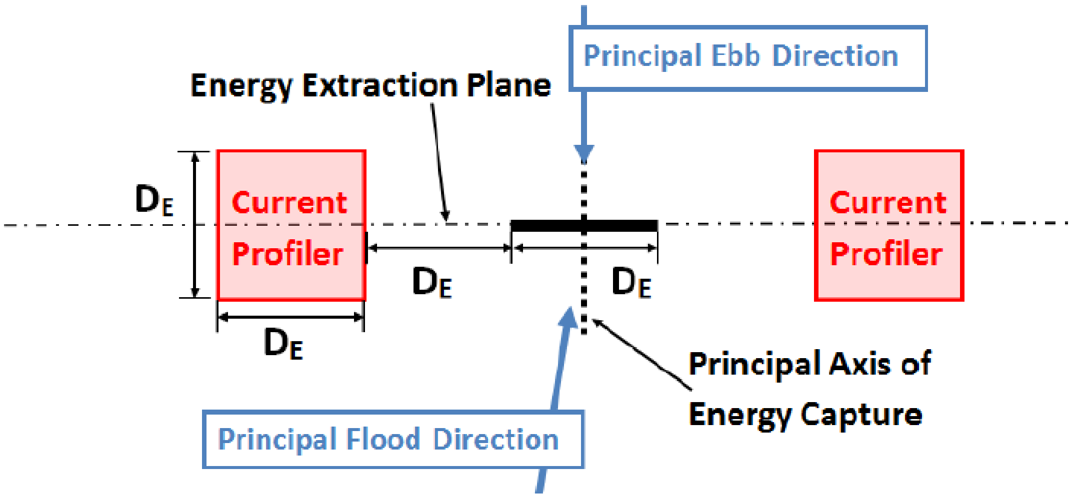

Figure 3-1 - Orientation B for current profiler deployment (plan view)

In the circumstance that the beam spread of the current profiler at the top of the capture area is greater than the required measurement volume diameter of $1D_E$, then the maximum and minimum distance requirements of $2D_E$ and $1D_E$ will not be mutually possible. The minimum requirement in this case should be the driving requirement, with an added tolerance based on the deployment accuracy (i.e. Minimum distance of ($1D_E$+deployment accuracy +/- deployment accuracy).

The maximum required should be modified to be within [$1D_E$ + beam spread at the top of the capture area + deployment accuracy (+/-deployment accuracy)].

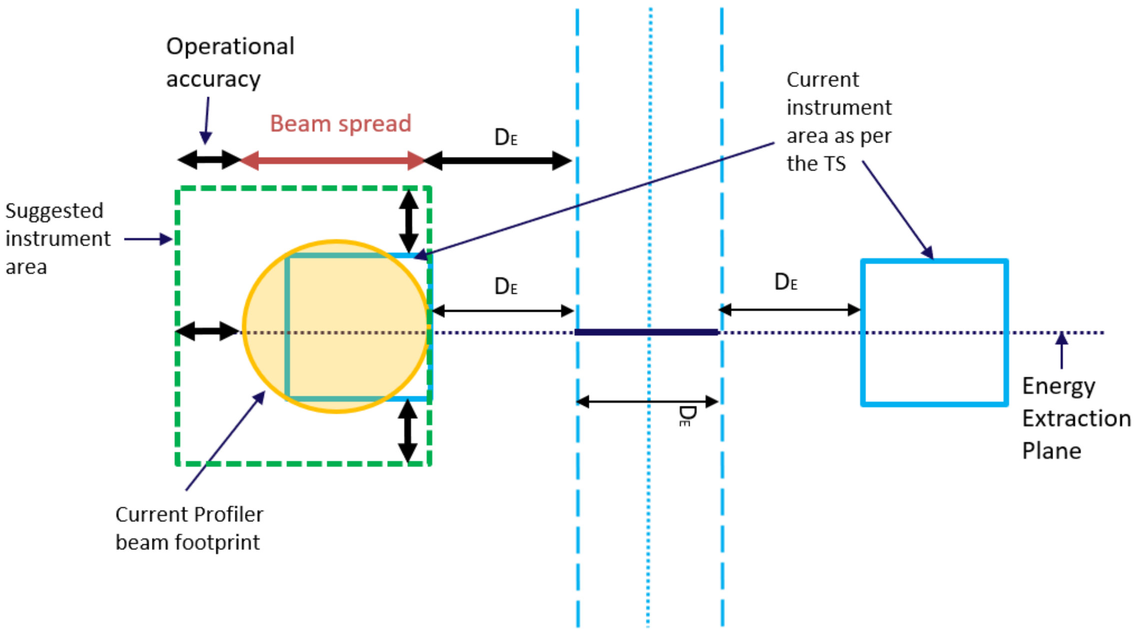

Figure 3-2 - Suggestion modifications to the current profiler deployment for orientation B when the beam spread is greater than the equivalent diameter of the device

In the instance that the principal flow directions are not opposite, the orientation B boxes may not be in the same place throughout the tidal cycle, as illustrated in Figure 3-3. In this case, the boxes should be redefined to accommodate both the ebb and flood tide. If there is no overlap between the boxes, the deployment box should be defined when the extraction plane is in the TEC mean position or putting the box halfway between the extremes. This is illustrated in Figure 3-4.

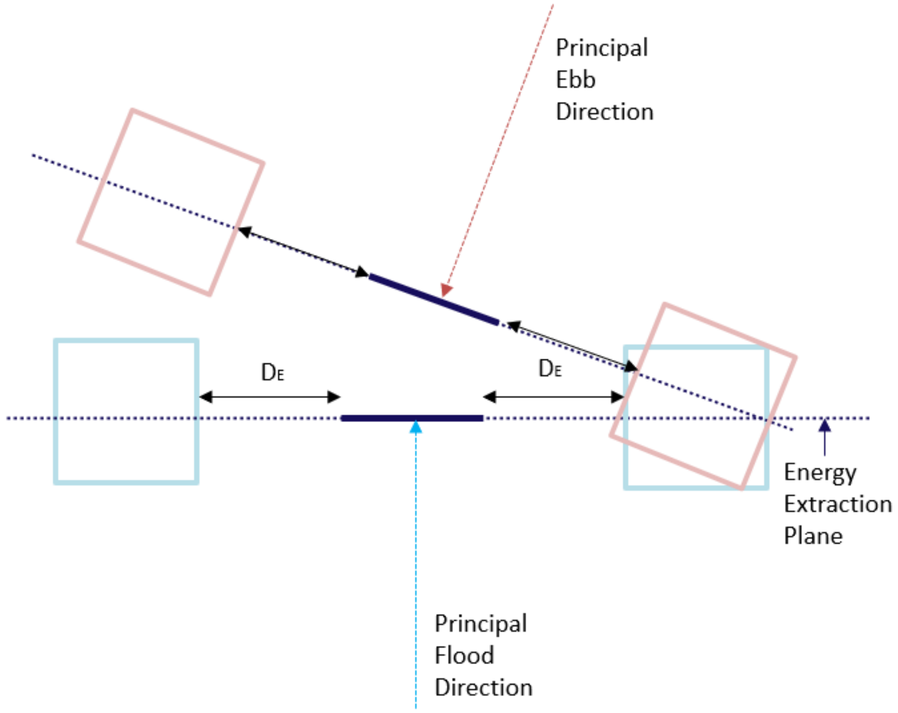

Figure 3-3 - Orientation B for current profiler deployment with principal flow misalignment

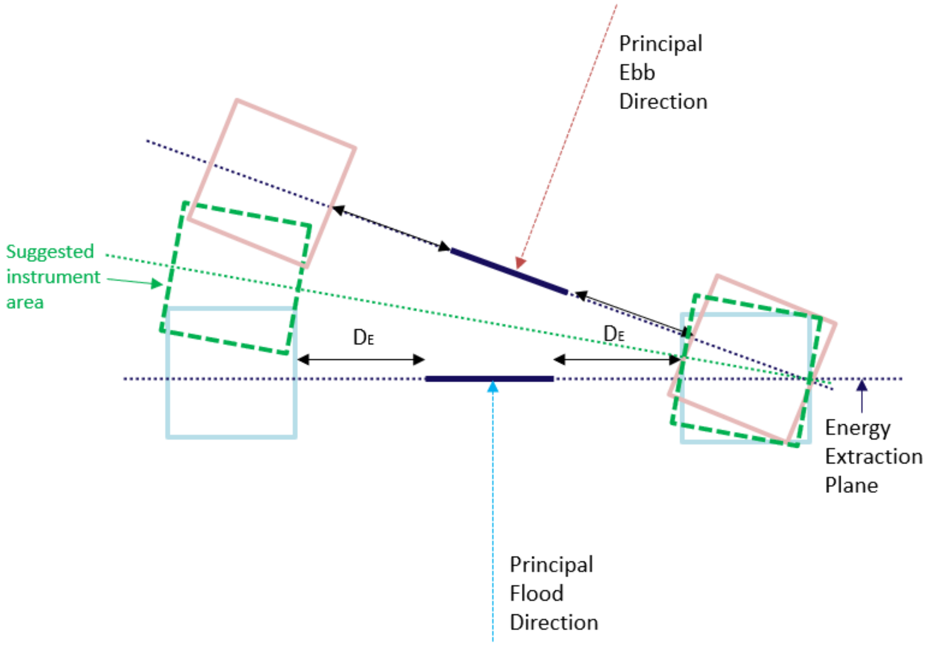

Figure 3-4 - Suggestions for measurement zone placement for orientation B for current profiler deployment with principal flow misalignment

Plan and side view figures illustrated the beam spread and ADCP positioning relative to the required orientations should be produced in the test plan and report. Figure 5-5 shows a good example of a plan view for this. A similar principle should be applied to orientation A regarding the width of the measurement zone.

3.2 TEC-mounted Current Profilers

If any of the following are true TEC-mounted ADCP's should be used:

- If the entire capture area cannot be measured completely by a seabed mounted ADCP, either because of side-lobe contamination or any other reason,
- If orientation A or B (IEC, 2013) are not practically possible using seabed mounted ADCP's,
- If seabed mounted ADCP's in orientation A or B (IEC, 2013) do not adequately measure the representative flow at the TEC position,
- Using seabed ADCP's is financially unachievable for the developer.

Ideally, TEC-mounted instruments should be incorporated into the design of the TEC prototype and not as an afterthought.

As already discussed earlier in this report, the current requirements for floating TEC's are likely to be impractical in most cases, in which case, justifications for alternative methods will be needed.

The justification evidence should demonstrate that the chosen location is representative of the global flow at the capture area whilst avoiding the influence of the TEC itself. As previously mentioned, there is no guidance or requirement into how to carry out a site calibration in the TS (IEC, 2013). There are a few reasons why some element of a site calibration may be needed:

- To characterise the local flow field of the TEC.
- To characterise the vertical shear profile in the capture area.
- To verify alternative measurement methods i.e. single point velocity meters.

3.2.1 Instrument orientation

Downward-facing TEC-mounted ADCP's are preferable to ensure a vertical profile with a minimum of number of bins equally to the value of the equivalent diameter and of a maximum 1 metre size, as stated in the TS (IEC, 2013). Where orientations A or B (IEC, 2013) cannot be achieved using a downward facing for reasons such as TEC, supporting evidence should be provided to quantify the implications of this deviation.

Any tilt on a downward facing instrument so that it is forward facing, should ideally be within limits that allow a vertical profile to be bin mapped with a compliant minimum of number and maximum bin size of 1 metre across the capture area.

If evidence can be provided that the shear velocity profile is reasonable constant, specifically in the capture area, then the minimum no. of bins and maximum bin size can be justified to allow greater tilt, or even, horizontal current profilers.

Attempts to 'patch' together separate current profiler data sets should be avoided.

3.2.2 TEC Local Flow Field Validation

Characterising the local flow field could be achieved by some form of sensitivity study through measurement or by numerical modelling, or a mixture of all. Numerical modelling may be used to estimate a valid measurement location, but this model should be corroborated by a reference measurement. The reference measurement would not necessarily have to be measured using a current profiler, though the accuracy and precision would need to be demonstrated to justify it as a reasonable tool for validating the model. The modelling would need to verify that the measurement position is outside of any significant impact due to the TEC's presence. Simulation and modelling will likely be costly exercise.

A sensitivity study using measurement could be done in the test set-up. A simple example would be to use horizontal ADCP's mounted on the TEC hub and this will collect current data that shows at what distance the onset velocity decrease in flow due to the TEC's presence.

3.2.3 Calibration Considerations

Beam or local reference frame coordinates should be used to avoid interference from the TEC hull or turbine. An alternative solution would be to link the ADCP to an external compass which is beyond the interference, although that is likely to be impractical and unnecessary. The TEC motion and positioning must be measured in parallel. Depending on the level of expected motion of the TEC, AHRS may be required to eliminate heading and tilt errors.

3.2.4 Alternative Instruments

If an ADCP is not practically possible to use then an alternative instrument can be used for incident flow measurement, if there is a validation campaign proving its effectiveness. Alternative devices could be single point velocity meters such as ADV's or ECM's. For this type of instrument to be considered effective it must be validated against an ADCP compliant with the points above.

In the paper by Frost et al. (2021), an ECM, ADV and ADCP were all deployed to measure at the same time. The current profiler was seabed mounted whilst the ECM and ADV were TEC-mounted on the SME PLAT-1 floating device. A similar method could be employed to validate TEC mounted single point velocity meters as the incident resource measurement sources for a full PPA. For this to be possible, it would need to be demonstrated that the vertical shear profile has negligible variance, and the chosen measurement point would need to be outside of the TEC flow field. These two last points may more easily be demonstrated using TEC-mounted ADCP's.

3.3 Reporting

Clear plan, front and side-view figures illustrating the incident measurement resource method should be presented in the test plan and report, and include:

- the TEC excursion, with mean and maximum positions;
- the incident resource measurement locations;
- measurement volumes;
- orientation A and B measurement boxes, where applicable;
- bins within the water column;
- the capture area;
- extraction plane; and
- beam spread.

Separate figures may be needed for the power performance testing and any pre-PPA studies needed to characterise the site and validate the methodology. Where sensitivity studies have been completed on the vertical shear profile of the TEC flow field, these should be appended to the test plan and report and graphical evidence supplied in the test plan and report.

Post-processing steps and corrections must be detailed to show how flow measurement at unit (ADCP) location is estimated to be applicable for TEC incident flow assessment.

4 Conclusion

This document reported on the current guidance in the IEC/TS62600-200 on how to conduct power performance assessments for floating TEC's and proposed further guidance on how to conduct this based on lessons learnt from in-practice testing. It is clear that the current IEC62600-200 technical specification does not cater well for floating TEC's. Clearer requirements and guidance are required so that repeatable and comparable power performance assessments can be carried out for floating TEC's. Consideration to the TEC-mounted incident resource measurement should be made early in the developers' design processes.

4.1 Recommendations

The following recommendations aim to highlight gaps and make suggestions, however, any alterations or additions to the technical specifications based on this deliverable should be done based on further justification or study.

- It is suggested that further guidance on measuring incident resource for floating TEC's is provided.
- It is recommended that flexibility is added to allow device specific solutions to the incident resource measurement methodology with requirements stated for justification evidence.
- It is recommended that a site calibration is required for TEC's over a certain size where the equivalent diameter puts the measurement zone far from the turbine. Where possible, that size should be determined by further study and not arbitrary. The site calibration should be designed to be as cost effective as possible.
- It is suggested that current profiler beam spread is considered into the measurement zone sizes and that it is required for the beam spread to be illustrated with the TEC position and current profiler position in the test plan and report. For orientation B, and the width of orientation A, (IEC, 2013) flexibility should be allowed for when the beam spread is greater than the equivalent diameter at depth of the capture area. Suggest making the lower requirement of $1D_E$ from the extraction plane lateral extent is the driving parameter but deployment accuracy is incorporated into it. The maximum requirement should be increased to incorporate deployment accuracy and beam spread.
- Where the principal ebb and flood flow directions are not opposite, further guidance should be given on how to define the deployment boxes. Recommend this is based on mean TEC position, unless that is not appropriate, in which case the box should be defined on the extraction plane when halfway between the two extremes of ebb and flood tide.
- It is suggested that the bin number and bin size requirements across the capture area for incident resource measurement are left to test team discretion. The minimum number of bins should be changed from 10 to equal to the value of the equivalent diameter, to avoid overly onerous data collection requirements for small TEC's.

- TEC-mounted horizontal ADCP's are deemed suitable if it can be demonstrated that the variation in vertical shear profile across the capture area is reasonably limited. A definition of what 'reasonably limited' means in this context should be stated in the TS as a guide, along with guid on how to carry out a sensitivity study to support this.
- If there is no negative impact on the measurement configuration, encourage the quantification of turbulence – no corrections should be performed but the results appended.

5 References

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Appendix A: ADCP Location Drawings

A – In-line (Figure 2): Two measuring instruments should be placed in-line with the TEC, one upstream of the TEC extraction plane on the flood tide and the other upstream on the ebb tide. These instruments should be placed such that the distance from the nearest external surface of the measuring volume (Figure 3) to the projected capture area of the TEC extraction plane is always greater than 2 equivalent diameters and less than 5 equivalent diameters. These instruments should be placed within ½ equivalent diameter of the principal ebb and flood direction streamlines coincident with the TEC extraction plane vertical centreline.

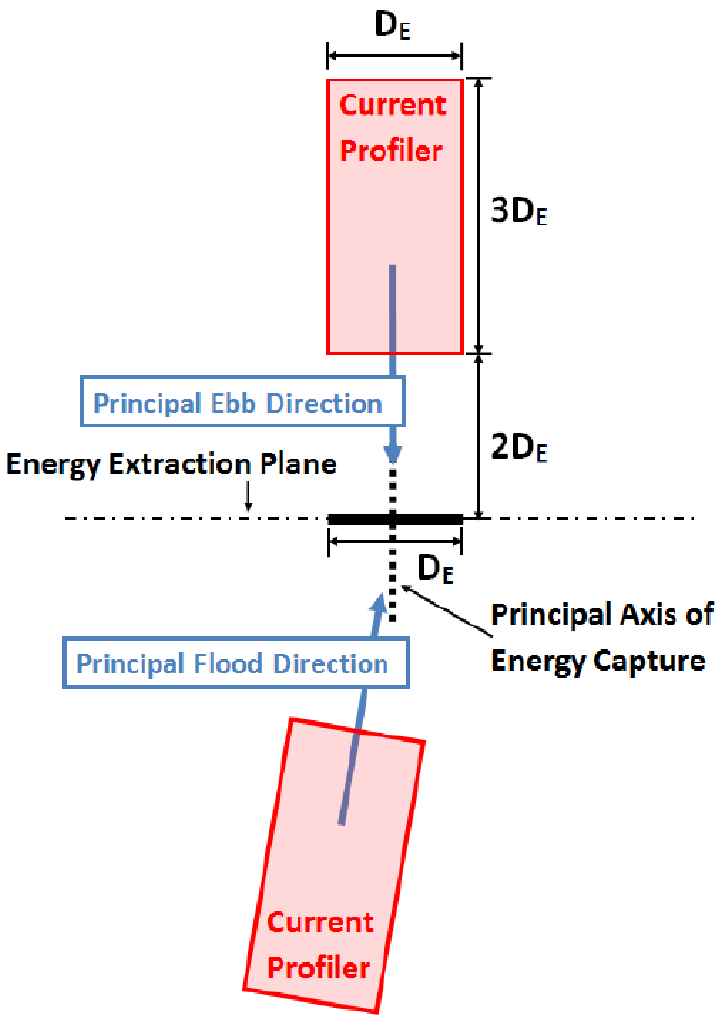

Figure 5-1 - Orientation A for current profiler deployment (plan view)

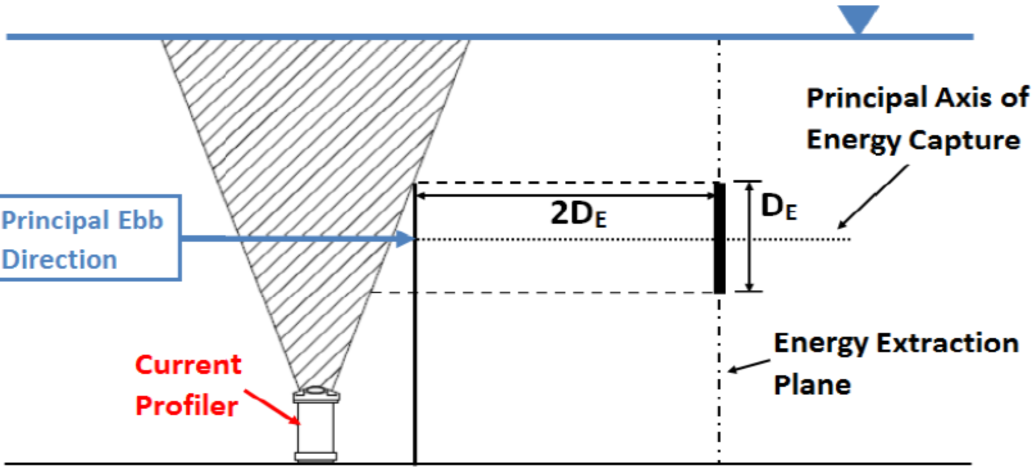

Figure 5-2 - Orientation A for current profiler deployment (section view)

B – Adjacent (Figure 4): Two measuring instruments should be placed adjacent to the TEC, one starboard and one port of the TEC extraction plane. These instruments should be placed such that the distance from the nearest external surface of the measuring volume (Figure 5) to the TEC extraction plane lateral extent is always greater than 1 equivalent diameter and less than 2 equivalent diameters. These instruments should be placed within ½ equivalent diameter of the TEC extraction plane lateral centreline. The linear average should be taken between any two measured values at equivalent water depths with identical measurement bin heights. The variation in measured axial velocity should be less than 10% between the two measuring instruments for the linear average to be considered a valid approximation of the flow at the energy extraction plane.

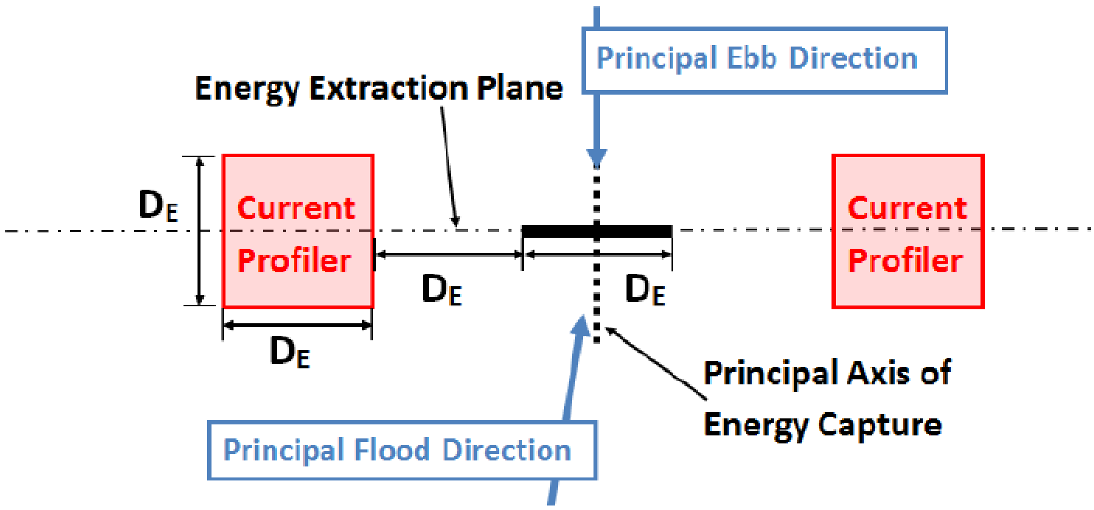

Figure 5-3 - Orientation B for current profiler deployment (plan view)

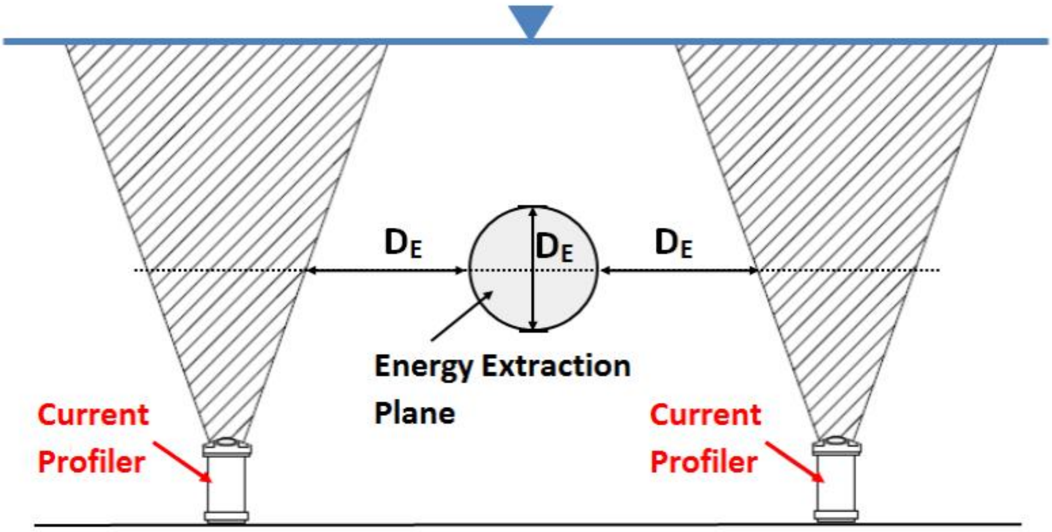

Figure 5-4 - Orientation B for current profiler deployment (section view)

Appendix B:MET-Certified Illustration of Current Profiler Positioning

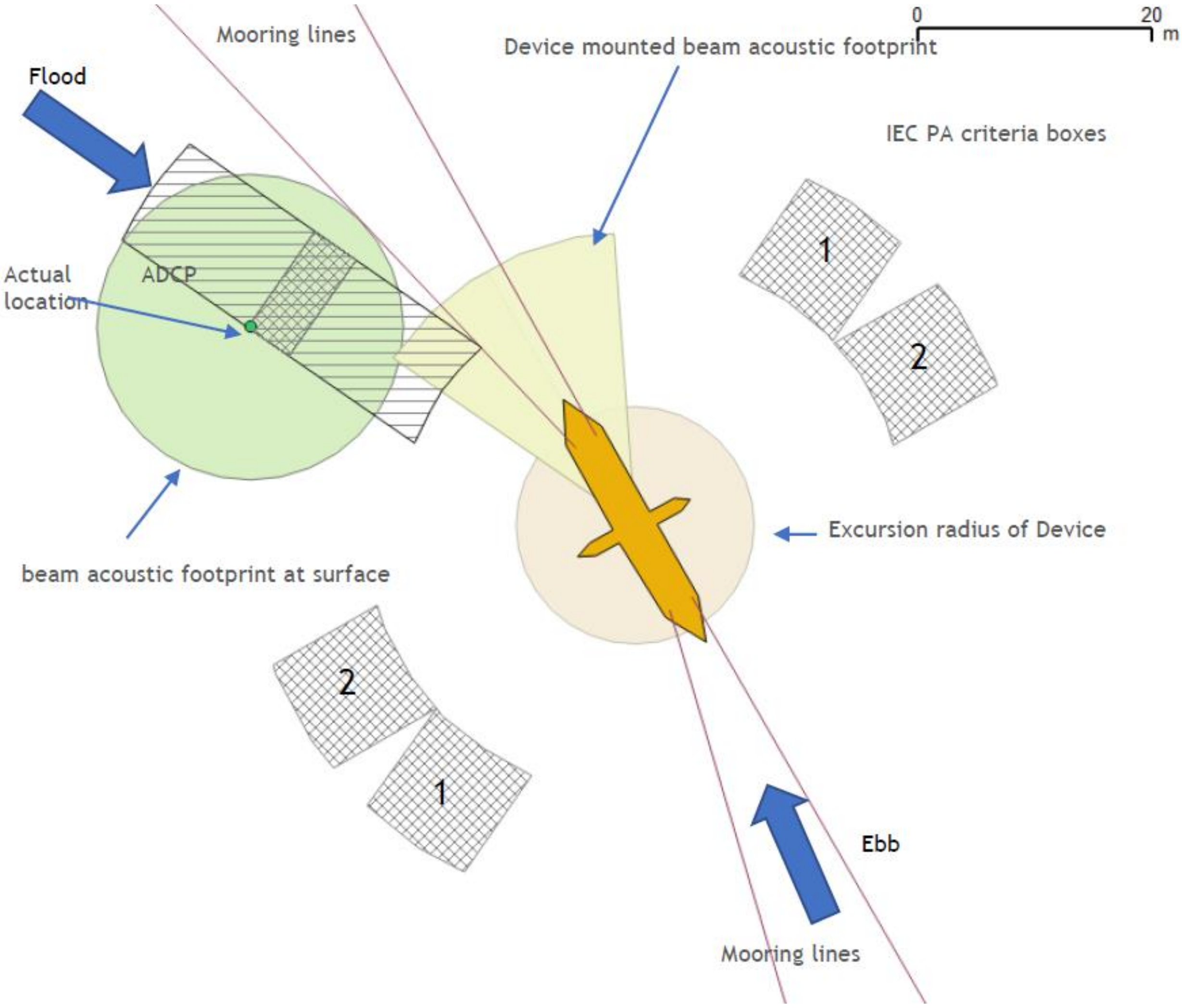

Figure 5-5 - Current profiler positioning (EMEC, 2018)