Principles of ADCP Deployment Methodologies

Penny Jeffcoate, Andrew J. Hunt, and Donald Sinclair

Abstract—**Acoustic Doppler Current Profilers (ADCPs) are regularly used for resource characterization in wave and tidal energy sites; however, methodologies and best practices are entirely dependent on the site characteristics and the assets available. EMEC have used their widely varied experience at multiple sites and locations to develop a review of methodologies and the pros and cons of different deployment styles for data acquisition.**

When deploying ADCPs there are a number of site criteria that must be assessed, such as seabed type, bed flow speeds, surface flow speeds, recovery windows (slack and weather), and water depth and range. These criteria can significantly affect the success or failure of marine operations, not necessarily for deployment but certainly for recovery. When recovery operations fail then projects lose assets (ADCP units and bed frames), data, and money (in hire/unit costs, and vessel hire for example). When the data is not recovered then this can jeopardise project success, wasting time, effort and funding.

Different deployment configurations and recovery techniques have been used for ADCP deployments. Equipment such as ground lines, acoustic releases, USBLs, and surface buoys are used to mark, locate, and/or recover devices. These are varied depending on a number of factors.

Based on multiple ADCP deployments to characterize resource for wave and tidal energy projects in Scotland, England, France and other sites, EMEC have reviewed different deployment methods and recovery techniques. There is a proposed set-up for deployments suitable for a number of active marine energy sites and suggestions for edits based on site characteristics and target data requirements.

Also, the use of ADCPs for other types of applications for marine energy deployments are discussed.

Keywords—**ADCP, Best Practice, Surveys, Marine Operations.**

I. Introduction

ACOUSTIC Doppler Current Profilers (ADCPs) operate based on the Doppler effect for measuring sound change sin flow fields. This allows water speed to be measured. When using multiple beams, and thus the flow speed at different points, this also allows water velocity direction to be determined. Two examples are Nortek Signature 500, and Teledyne Sentinel V:

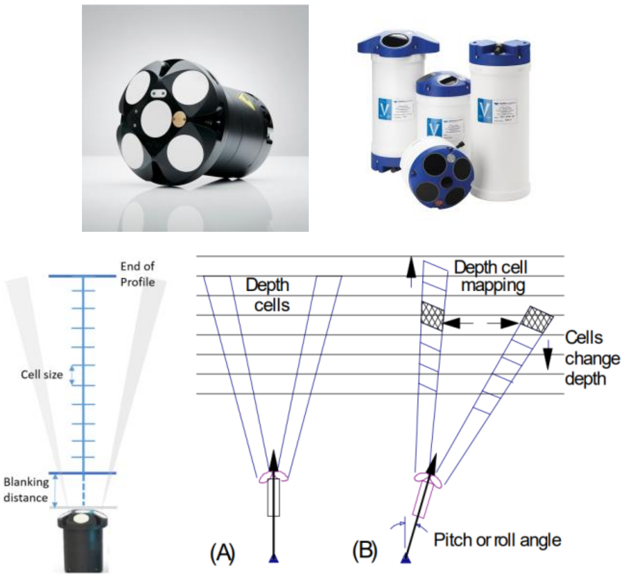

Fig. 1. Nortek (left) and Teledyne ADCPs (right) and examples of through column measurement

ADCPs are commonly used in the tidal energy industry to assess sites for resource, and concurrently with tidal energy devices to measure power performance (for example [1][2][3]).

This paper discusses some of the considerations when deploying an ADCP including lessons learnt by EMEC from field deployments.

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II. Data Collected using ADCPs

ADCPs have a number of sensors that allow then to collect data. The main sensors and their uses are summarised below.

A. *Beam Transducers*

The velocity is measured using beam transducers. These operate on the Doppler principle and record velocity a long each beam. Velocities between beams are then resolved to give local or global velocity in XYZ or ENU directions. Beam spread means that with increasing depth the velocities are averaged over an increasingly large area.

B. *Temperature*

Temperature is measured using a thermistor. Temperature affects speed of sound and thus the working principle of the Doppler effect. Temperature may also affect flow dynamics and other items of interest for research, such as fish and marine mammal presence through the water column.

C. *Compass*

Typically, a magnetometer or fluxgate compass is used to record the heading of the ADCP unit and thus the global velocity direction of the water column measurements.

D. *Tilt*

This is measured by an accelerometer, and will show if the unit has moved, by animal interference or tide and wave movement, thus affecting velocity measurements.

E. *Pressure*

This could be measured using a piezoresistive measurement. Pressure gives the depth that the unit is, and thus tide and wave height over the unit. This is very important for floating devices, or devices that change position in the water column, so that the swept depth can be known.

F. *Clock*

The time is measured as this is related to the velocity measurements. Drift is a consideration for deployments and should be corrected using methods described in IEC 62600-201.

G. *Wave Tracking*

Some ADCP units use a wave tracking sensor to measure waves. This is dependent on unit type and deployment priorities. This gives better wave metrics than the pressure sensor.

III. Deployment Considerations for Resource Assessment

IEC 62600-201 [4] states the deployment criteria for using ADCPs for resource characterisation and yield/Annual Energy Production (AEP) prediction. These guidelines should be followed wherever possible. Some of the detailed elements of this are discussed below, with reference to bed mounted ADCPs for resource data collection.

When deploying an ADCP for data collection there are a number of parameters that will vary depending on the nature of the site, equipment available, and preferences for data to be collected. The following sections outline some of the considerations that must be examined prior to deployment.

H. *ADCP*

The parameters that can be changed for an ADCP include unit type, deployment file, and sampling strategy. Some examples are given below:

1) Unit Type

ADCPs for resource assessments are commonly 4-beam or 5-beam units. These operate so that data can be collected in 3 dimensions through the water column. The key difference between the unit types is that 5-beam ADCPs are better for turbulence measurements, and also provide redundancy for the pressure sensor when measuring depth.

2) Deployment File

The deployment file must be written to best capture the needs for a specific deployment, whilst balancing parameters such as battery and memory, and ping frequency.

First and foremost, it is recommended that a bed ADCP for resource assessment complies wherever possible with IEC62600-201.

Duration should be specified to accommodate length of intended deployment, plus redundancy for lost operations, such as a couple of days in case a low/high water slack window is missed, or a couple of weeks in case a neap recovery window is lost to weather, so that data can still be collected whilst the unit is deployed. The IEC 62600-201 recommends 90-day deployments where data will be used for harmonic extension for yield and Annual Energy Production (AEP) calculation.

Depth can be defined to cover the intended rotor swept depth. For floating devices, it is important to consider how this will change with depth at site, tidal height, wave climate, and swell or pressure. The top few meters are usually lost from a data set i.e., the quality is too low to give representative results, due to surface reflections and interference.

3) Concurrent Sampling

Modern ADCPs can run two data sampling plans concurrently. These are beneficial when considering different constraints such as resource and turbulence.

Resource data collection is better to collect continuously at an intermediate ping interval (1s – 10min), sampling frequency (<20s) and averaging frequency (2 – 10min) [4].

Whilst it is ideal to collect continuous high frequency data for turbulence statistics this is not always possible. Turbulence data can be collected in bursts, such as 15min intervals hourly, though this may affect the ability to determine some turbulence characteristics. The sampling frequency for turbulence measurements is dependant on the site conditions, particularly flow speed and approximate length scales; at Falls of Warness it is approximated that sampling frequencies of 2Hz or greater can be used, and ideally up to 8Hz to avoid aliasing.

Plans can be balanced to maximise the data collected to increase the amount of information collected in a single deployment, thus reducing number of surveys required for site characterisation, and thus cost for each site parameter.

I. Equipment

The following considerations should be assessed for the auxiliary deployment equipment:

1) Frame

The frame should be designed to give a stable base in high flow regimes, with no blocking of the ADCP beams.

As stated in IEC 62600-201 it is important to use a non-ferrous frame; this is to reduce the interference to the internal fluxgate compass, as incorrect headings will affect both flow direction ad speed measurements. Compasses must be calibrated to reduce any deviation. This step is particularly important if using the data collected to define orientation for device deployment, such as non-yawing turbine direction, or mooring spreads.

Additionally, the frame should be gimballed to ensure that the ADCP is pointing vertically through the flow. There is a limitation on the gimbal angle, so frames should be deployed as flat as possible on the seabed, but gimbals help with alignment to the vertical. It is recommended to use a post-deployment mechanism to check that the unit Is flat, such as diver (where depth allows) or drop camera.

Note that there will be marine growth on units, but this should not interfere with data recording with the correct frame geometry (Fig. 2, Fig. 3). For long term deployments anti-fouling paint and patches can be used, though marine growth is found to be reduced on transducers, most likely due to their material and frequencies of operation.

2) Connection Jewellery

Ground and recovery lines are connected to frames using connection jewellery. To reduce deviation it is recommended to use non-ferrous materials in the initial area, e.g. using 2 - 3m lifting strops connected between the frame and the ground chain. It is important to use non-magnetic stainless steel for shackles to reduce compass deviation, reduce metallurgic reaction with the non-ferrous frame, and reduce marine corrosion for long term deployments; failure to do so could result in metal degradation as shown in Fig. 4. If shackles are worn then it could create difficulties on recovery, such as connections breaking, and units lost.

Strops and shackles should be secured with additional cable ties, Loctite (or similar), and split pins to ensure connection do not work loose during long deployments.

No connection jewellery or lines should clash with the beams or cause any other interference to data collection.

Fig. 2. ADCP frame showing marine growth from long term deployment.

Fig. 3. ADCP frame and ADCP unit showing marine growth from long term deployment.

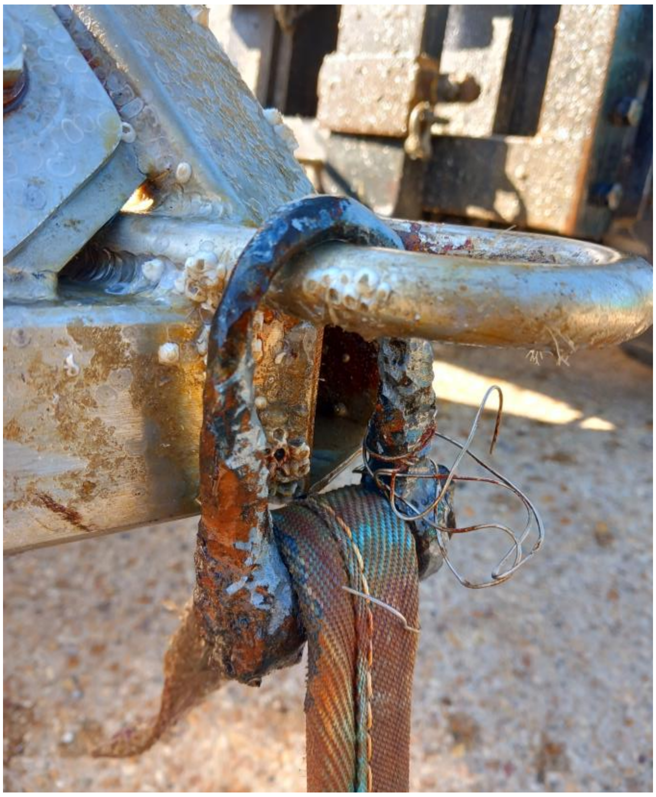

Fig. 4. Worn shackle from long term deployment. Also shown metallurgical reactions, marine growth on strops, and securing wires.

3) Ground Lines

Ground lines can be used to secure the units, and as a recovery technique, though this will be described later. Ground lines should be specified so that they do not float or billow excessively, in a way that could interfere with the signal, cause failure through chafing, or movement of the ADCP is the line is snagged. Ground lines can be synthetic ropes, but chain can also be used or a hybrid of chain and synthetic rope.

4) Securing Method

ADCPs are usually held on station using their own self weight, but in some instances station-keeping methods can be used. The securing method is dependent on the bed type and the flow speed. Typically for ADCP deployments in high flow the ground is scoured and so drag embedment anchors are not used. Gravity based systems, such as railway wheels or chain clumps, can be used to create a solid anchor point. For more permanent systems other fixing methods could be used such as direct embedment anchors, e.g., screw anchor piles, or rock bolts / anchors.

J. Marine Operations

Success of marine operations are dependent on many factors, but the following should be considered when planning method statements for specific deployments.

1) Recovery Options

When deploying an ADCP it is imperative to consider the recovery method. This is possibly the most important element when specifying the equipment and marine operations. This is affected by different site criteria. for

TABLE I
EXAMPLE RECOVERY TECHNIQUES FOR ADCPS

Method	Pros	Cons
Divers	Reduces risk of equipment failure	Only in select sites
Ground line trawling	Commonly used marine industry technique e.g., in cable laying	Destructive to seabed and time consuming
Permanent riser lines	Surface marker for visibility and no need for sub-surface equipment	Risk of damage from props or pulled under in flow, and could interfere with data
Acoustic release	No data or surface obstructions	Risk of equipment failure
Recovery cone	Easily identifiable target and connection jewellery	More complex operations for deployment

example, in shallow, slow water sites with large slack windows the ADCP could be deployed stand alone and a diver used to connect recovery lines; however, in deep, fast flow with short slack windows divers cannot be used and quick recovery methods should be used. Some recovery techniques examples are given below in Table 1.

2) Vessels

Depending on site conditions and accuracy criteria then different vessels can be used. For example, if over boarding only single unit in shallow water with no auxiliary equipment then smaller vessels can be used as the unit will be lighter and simpler.

Typically, multicats are used for operations. These use crane or A-frame for deploying the units and lines/anchors (Fig. 5). A mooring spread is useful for holding station, especially a 4-point spread for high positional accuracy, or operating through a tide, but not essential. A 2-point spread can be used for holding vessels into flow and panning / ferry gliding across flow.

Fig. 5. Crane operations on multicat for over boarding ADCPs

3) Slack Window and Tide Height

The slack window and tidal height will define the length of time and the slack window to target. A long slack window allows more time for operations, whereas small windows mean that operations must be well planned and efficient. Most tidal sites have asymmetric windows, i.e., the HW window may be longer than the LW window or vice versa. Additionally, if a site is particularly deep or has a large range it may be beneficial to target the LW slack to make operations easier.

4) Positioning Accuracy

If positional accuracy is important, then high accuracy methods for deployment should be used. These could include slack deployment, use of DiffGPS, USBL positioning, and drop back methods.

ADCPs should be deployed at slack water so that crane wires are vertical, giving higher certainty that the ADCP position relative to the crane head is known.

A GPS, or preferably Differential GPS unit can be placed on the crane head, so that the ADCP position is recorded. This position can either be recorded directly or the offset to vessel GPS reading can be calculated.

A USBL mounted on the ADCP frame and a receiver on the vessel could also give range and bearing been the two units, so that the assumption that the crane wire is vertical is accounted for.

Four-point vessel moorings give highest positional accuracy of the vessel and thus accuracy of the ADCP. It is recommended to get an "as laid" position using either the methods described above, and/or an ROV or similar.

5) Orientation Accuracy

Orientation accuracy is important for turbulence measurement. ADCP beams must be aligned with streamwise and perpendicular to the flow for best measurement [5].

The vessel mooring or chain clump could be deployed upstream of the intended position and then the vessel and ADCP dropped back in line with the flow to give the desired ADCP orientation. It is important during set-up to ensure that the ADCP is aligned correctly in the frame and the connection jewellery is aligned.

6) Concurrent Units

Deploying concurrent ADCPs gives data that can be used to assess spatial variation across a site, and different flow regimes.

Putting ADCPs too close could result in beam clashing, noise interference, and thus data loss.

Correspondence with Nortek and Saderet (Teledyne) suggests that their units must be spaced at least 3 times the deployment depth to avoid interference, e.g., for a deployment of 60m, concurrent units should be spaced at least 180m apart. This will depend on the unit type, frequency, beam angle and beam spread.

Different unit frequencies could be used, but the efficacy of this is not known by the authors.

K. Additional Information

There are several other considerations for deployments including additional equipment. Some criteria are discussed below.:

1) Consistent Conventions

When designing marine operations, it is important to use a single convention to avoid error. This could be for location e.g., using WGS84 across all planning and vessels, or coordinate reference systems, e.g., using ENU global coordinates rather than local coordinate systems.

2) Survey Equipment

Survey equipment can be designed and used for recovery operations. For example, EMEC's SurveyFin uses a SONAR and cameras to locate ground lines for certain deployments (Fig. 7, Fig. 6).

3) Regulatory Constraints

Regulatory framework may also drive preference for choice of configuration. For example, large, lit navigation buoys in situ on the surface may be preferred over more complex, costly methods, but in other areas of high traffic flow the regulator may not allow any restriction to navigation.

Please note that there are many deployment configurations and equipment options depending on site and equipment, but those presented are based on EMEC experience.

Fig. 6. EMEC's SurveyFin with dive camera, Spyball camera, and SONAR

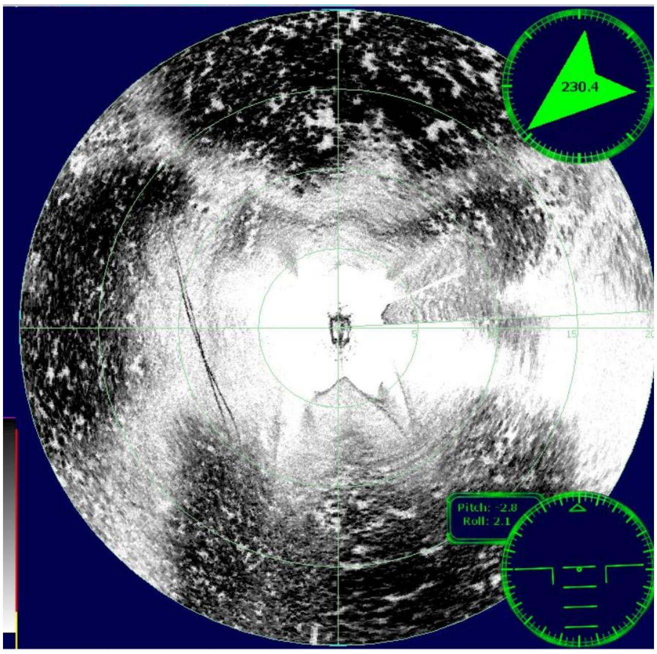

Fig. 7. SONAR signal of SurveyFin and ground lines to left of unit

IV. Recovery Examples

L. *U-shape Deployment*

Firstly, a site with low or high flow speeds and no vessel traffic could use riser lines as principal recovery method. A second recovery method for redundancy could be long ground lines for trawling. The U-shape configuration can be used.

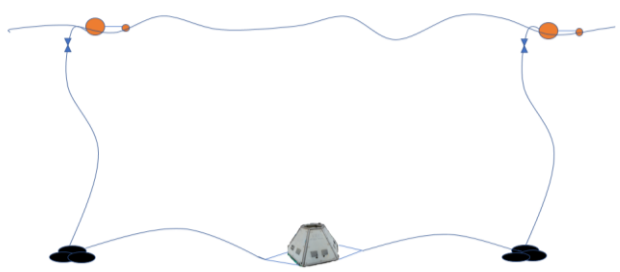

Fig. 8. U-shape configuration - ADCP, with ground lines, clump weights, and risers

- The ADCP is housed in a bed frame.
- Slings connect the ground lines to the frame to provide a lifting bridle if necessary.
- Ground lines have some buoyancy and thus billow, to provide a grappling point for recovery if necessary. Lines are rated such that the ADCP and chain clumps can both be lifted using this line. The ground lines are long enough that each bed element can be lifted alone, i.e. the distance between the chain clump and the ADCP is greater than the depth.
- Chain clumps give a securing method to ADCP, maintain the ground line in a stretched-out configuration, and can be used to align the ADCP during deployment (further details below).
- Floating line is used for the riser lines (e.g., polypropylene). The lines are long enough that the buoys come to the surface under slow flow speeds, and are rated such that the chain clumps can be lifted using this line.
- Surface floats are rated such that they bring the riser line to the surface in slow flow and at any state of tide height but are not crushed when pulled sub-surface in higher flow speeds.

M. *Buoyless Deployment*

A site with high vessel traffic typically cannot use surface buoys, either due to regulatory constraints or high risk of loss. A buoyless deployment with groundlines for grappling could be used.

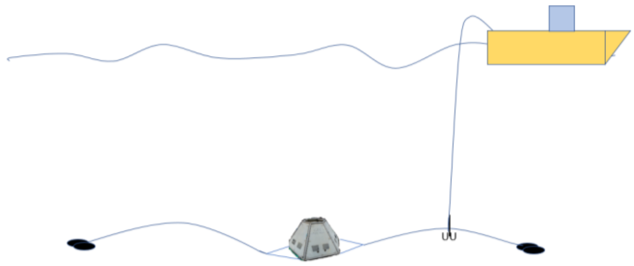

Fig. 9. Buoyless configuration - ADCP, with ground lines, clump weights, and grapple recovery

- Groundlines have enough slack to allow grappling hook to snag the groundline and recover clump to surface.
- This is not recommended for deep water or rocky seabeds due to the difficulties in manoeuvring the grappling hook.
- An ROV could be used to thread a messenger line.
- A back up acoustic release could be mounted on the frame.

N. *ROV/Diver*

In low flow, shallow sites ADCPs can be deployed with no recovery equipment, and divers or ROVs can be used to connect recovery lines. Diver recovery can be regarded as the least favoured method due to risk and expense. Area specific dive regulations should also be taken into consideration.

O. *Acoustic Release*

An acoustic release can be used as a principal recovery method, though there are some concerns with the practice. The release could be triggered early, resulting in lines interfering with the signal and thus data errors, or loss of the recovery buoy and line. Alternatively, when the release is triggered, it may fail and so the line is not released to the surface. A secondary recovery method must be considered prior to deployment, to be used in the event of acoustic release error.

V. OTHER DEPLOYMENT TYPES FOR ADCPS

Though ADCPs are most commonly used for resource assessment to comply with IEC 62600-201, the units are also regularly used for performance assessment [6]. IEC 62600-200 defines the methodology for using seabed mounted systems for power performance assessment, though this is most suitable to static, bed mounted tidal turbine systems (note an updated standard is due to be released but is not available at the time of writing). There are several options for using an ADCP for other site and device criteria, as detailed here.

P. Vessel-mounted, Down-facing

When considering an array, or a device with a large footprint, the spatial variation is important for accurate resource assessment and yield estimation. Spatial variation can be assessed using numerical models, which in turn use bed mounted ADCP data for validation and verification, but vessel mounted units can also be using for moving surveys.

When conducting vessel mounted surveys of an area it is important to gather information about all states of tide in neaps and springs at as many locations as possible.

Transect surveys can be used to give variation along a line and allow a large area to be covered. This is good for general information about an area, but post-processing is difficult to account for the advancement of the tide during the survey, i.e. at a point in the area the data may be collected at HW+2 but at another at HW+2.5, so the difference in tide time must be analysed.

Another option is to have the vessel static at a single point to sit through a tide cycle, then move to another location. This gives greater detail at discrete locations but is more time and thus cost intensive.

The type of surveys depends on the stage of investigation, so whether getting a general impression of an area for suitability and feasibility assessment, or whether checking the exact data at a precise position. This can also be conducted concurrently with a bed mounted survey, so that the data at a single point can be used for estimation at other positions for future yield prediction, for example.

In all vessel mounted surveys the vessel motion, pitch, roll, yaw, must be accounted for. Global ENU coordinate systems may thus give the most accurate data measurements.

Q. Device-mounted, Down-facing

Depending on the device and structure type an ADCP could be mounted on down facing through the water column. This has a number of advantages, particularly for floating systems.

When using a bed mounted ADCP for a floating tidal device the water column being recorded may not be directly upstream from the rotor, due to device yaw and sway. The IEC standards account for this by having a window for deployment (2 – 5 effective diameters, D_E upstream and 0.5D_E laterally) but small amounts of incoming flow angle may affect performance depending on rotor type. Also, there is spatial variation between ADCP measurement volume and rotor plane depending on device configuration, mooring spread (and inherent marine operations limitations to adhere to standards), and beam spread with depth.

Therefore, a device mounted system would allow water velocity that already has device yaw and sway included to be measured, a smaller beam spread with depth, and a consistent distance from the rotor plane.

The data could also be used for other information, such as water velocity through the water column below the device for marine life ecological surveys, and bottom tracking for more accurate depth measurements without surface interference.

The main constraints of device mounting, depending on device size, is covering the rotor swept depth (due to blanking distance compared to tip depth) and distance upstream to be out of the pressure influence of the rotor (2 – 5 D_E).

R. Device-mounted, Inclined

ADCPs could be mounted on a device and inclined to try to cover the swept depth at an appropriate distance upstream. This would reduce the spatial uncertainty compared to a bed-mounted system, and reduce the pressure influence of the rotor, compared to a down-facing system. This configuration has not yet been tested and published for a tidal device.

S. Nacelle-mounted

In order to determine the region of influence of the rotor pressure field, and measure the exact incoming velocity, then a nacelle-mounted system could be used. For a 5-beam ADCP the centre beam would measure the exact incoming hub height velocity, and the four inclined beams would give some information over the swept area, though the data accuracy is lowest in this orientation. The rotation of the nacelle would also have to be considered, though this would not affect a single central beam.

T. Instrument Verification

Any time multiple instruments are mounted then they can be compared to one another [3]. This can be used to assess local influences such as flow regimes about mounting structures, and compare bed mounted and vessel mounted data sets.

VI. CONCLUSIONS

The IEC standards provide a good basis for the requirements for using ADCPs for data collection, but the detail around deployment and recovery mechanisms must be considered on a site, device, and parameter basis each time. This paper has discussed some of the considerations and options for deploying ADCPs.

1) Sensors utilised, unit type, and deployment plans will depend on the deployment type and the data priorities; there are some advantages for using 5-beam units where possible.
2) IEC 62600-201 and -200 should be followed where possible for resource assessment and power performance.
3) Frames and bed-securing systems should be considered from the outset, with particular focus on site conditions and recovery methods.
4) Marine operations are complex and difficult, and so should be streamlined with data priorities and site constraints in mind from the outset.
5) ADCPs can be used for a variety of applications aside from bed-mounted resource measurement, depending on device configuration and data requirements.

Despite best efforts and intentions, there are always ADCP unit losses or data failures. This unfortunately is the nature of marine field operations. Minimising these losses is critical for tidal energy site success.

With every deployment of an ADCP there are lessons learnt, even for experienced site providers, surveyors, and developers. It is important to share knowledge and best practices wherever possible to reduce data losses, and thus reduce the cost of data gathering, and ultimately the Levelised Cost of Energy of tidal energy projects.

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