

SYSTEM DEVELOPMENT FOR PROFILING DEEPER WATERS IN SUPPORT OF THE OIL AND GAS INDUSTRY

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ABSTRACT- In recent years, the exploration and production activities of the oil and gas industry have been expanding into deeper water. With this expansion came a demand for reliable and continuous ocean current measurements throughout the water column over deeper ranges than previously required. Meeting this demand has required developing new systems that combine new instrumentation, deployment schemes, and real time software for data display and forecasting.

This paper discusses some of the problems that had to be solved in meeting this new demand. Operating acoustic instrumentation such as ADCPs around oil and gas platforms has to combat both acoustic noise sources and obstacles in the water. The noise sources include plant and platform noise as well as flow noise generated by thrusters. The noise problem worsens as the acoustic systems operate at lower frequencies. Submerged obstacles that can interfere with the ADCP's acoustic beams include legs, lines, and risers.

In this paper, we discuss data and field experiences from collaborative work between RD Instruments, Fugro/GEOS, and Shell E & P Technology Company. The project involved Shell's working with Fugro/GEOS as system integrator to deploy RDI's state of the art 38 kHz Phased Array ADCP. Innovative aspects of the work include new instrument technology--hardware & firmware--different deployment schemes to optimize data, and specific software development for real time data display of the current profiling and current forecasting in support of offshore oil and gas deployments.

I. INTRODUCTION

For the last ten years the exploration and production of oil and gas reserves have increased in the deep waters at the edge of the continental shelf. Deep water exploration deals with most of the environmental demands of shallow water exploration plus the added significance of complex shelf edge area currents. These currents are often strong and variable and have caused many operational challenges in the exploration and production of oil and gas reserves.

Requirements for current information include: riser deployment, vessel/rig selection, and ROV operation, station holding and ship loading. Requirements like these have led the industry to

demand real time current measurements throughout the water column. The measurement of real time deep water currents requires instrumentation with commercial availability, economy, ease of installation, performance and reliability. RD Instruments has developed a long profiling range 38 kHz Phased Array (PA) ADCP in response to these requirements. This instrument uses a patented (Patent # 5,808,967) 2-D phased array transducer with selectable processing modes.

II. SYSTEM DESCRIPTION

The PA-38 ADCP for oil rig current monitoring is similar to the PA-38 ADCP developed for moving vessel application, which has been described in separate publications. The features emphasized in this paper will be those most applicable to oil rig issues.

The basic ADCP unit consists of a transducer assembly coupled to a topside electronics unit and a data processing unit. The transducer assembly is a novel 2-D planar phased array assembly which simultaneously emits and receives up to four beams, oriented in the conventional ADCP Janus configuration.

The electronics unit connects to the transducer assembly, supplies power to all modules, receives, processes, and controls all functions, and interfaces to and from the unit, including the rig data processing system.

2-D Phased Array Transducer Description

The 2-D phased array transducer is the enabling technology that makes it possible to increase ADCP profiling range by operating at lower acoustic frequencies than practical with larger conventional "piston" transducers. The planar phased array transducer has a flat face as it is constructed out of hundreds of ceramic elements and other special materials aligned geometrically in one plane. (Figure.1) Housed inside the top-hat of the transducer housing are an optional flux gate compass and an attitude sensor for applications where the transducer is not fixed to

the rig.

For a given range and frequency, a 2-D planar 38 kHz phased array transducer has an order of magnitude smaller volume as compared to a Janus configured transducer of similar performance. This transducer has a housing diameter of 915mm and is 121mm high. The housing is made of naval bronze with a weight in air of 248 kg. The array is rated for 300 psi at this time.

The array beam pattern, like any other ADCP transducer, is a critical factor for an ADCP's performance, particularly in rig applications where highly reflective underwater objects are common. Therefore, narrow beams and high off-axis rejection of interference targets is essential for accurate current measurement. The 38 kHz PA unit has a 2-way beamwidth of approximately 4 degrees and cross beam rejection of typically better than 35 dB. In addition, improved beam suppression techniques are currently under development.

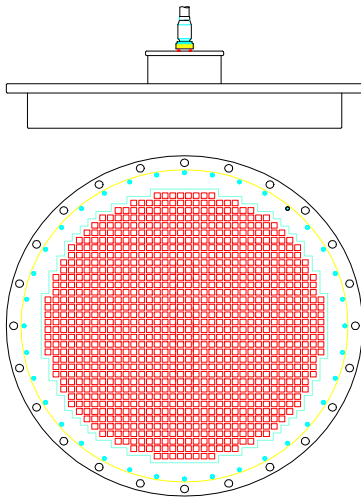


Fig.1 Transducer Design

The electronics unit is contained in the same 19" rack mountable chassis used in RDI vessel mounted ADCPs.

The unit uses a 32-bit floating point digital signal processor (DSP) and a Field Programmable Gate Array (FPGA) to control and execute all transmitting, receiving and data processing functions. Four serial communication ports are available for the rig sensor and data processor interface. Currently, the PA-38 ADCP operates in a pulse coherent "Broadband

(BB)" mode, operating at approximately 5% fractional bandwidth.

In the future it will also operate in a conventional but improved pulse incoherent "Narrowband" (NB) mode when longer range is preferred over the higher resolution (BroadBand) of the operation. The NB-mode employs iterative narrow band processing to avoid velocity measurement errors present in previous RDI narrowband ADCPs. A signal bandwidth on the order of 0.5% is used, providing approximately a factor of 100 (20dB) improvement in the signal-to-noise (S/N) ratio. Hence, the NB-mode of operation will increase profiling range in addition to the range increase due to the lower system frequency. The user has the choice to select either mode or to alternate between operating modes depending on the application requirements.

Possible Enhancements

There are several system enhancements scheduled for the PA-38 ADCP to provide improved operation on rigs.

Image beam and adjacent beam suppression algorithms are being developed for both BB and NB-modes of operation. These algorithms are designed to suppress the image and adjacent beams by at least an additional 20 dB beyond the level of conventional piston transducers. The effect is a reduced cross talk that will reduce the velocity bias effect due to non-uniform scattering between beams. This is commonly encountered in rig applications with submerged objects such as UUV's drilling risers, & mooring cables.

The implementation of a hard transducer face will reduce the damage from long term bio-fouling and decrease the chances of handling damage to the transducer face in rig applications.

To better deal with rig and surface noise and to improve its versatility, the PA-38 ADCP transducer and electronics will be designed to operate at depths of over 1500 meters. This will allow the user the option to deploy the instrument either downward facing from the rig or pointing upward with near-bottom deployment. This upward application typically will provide longer profiling ranges than downward deployments because of typically higher near surface biological backscatter concentration at the end of the profiling range and due to the reduced rig noise.

The ability to shut down transmit on any one beam electronically will also be provided. This will improve ADCP operation on certain types rigs (TLP) where it is impractical to orient the four beams to avoid acoustic interference from cables or risers as discussed below.

III. OPERATING ENVIRONMENT

Deep water exploration and production of oil and gas reserves have presented many operational challenges for companies active in this business. With over 60 new deep water rigs being built at an investment of more than \$12 billion, these oil companies are committed to solving the problems before them. The ability to acquire, display, interpret and disseminate current information in real-time can assist greatly in operational planning, resulting in a safer working environment and providing potentially large cost savings. Shell E & P Technology Company with 14 deep water rigs, the most in the industry, has worked closely with Fugro/GEOS to better understand this unique environment for successfully operating ADCPs.

Each rig offers its share of technical challenges when deploying the PA-38 ADCP. The experience and documented processes that Fugro/GEOS has developed in general ADCP rig deployments has been essential in the many successful PA-38 ADCP in rig operations today. (Fig.2)

With the global oil industry requirement to explore and produce in deeper waters using mobile rigs, the need for currents measurements over the entire water column has become a priority.



Fig. 2 Deployment of a PA-38 ADCP on an Oil Rig

The key factor in determining measurement range is the transmission frequency of the

instrument. A 75 kHz BroadBand ADCP can achieve a range of approximately 500 - 600 meters in optimal conditions. Until recently, this performance has been adequate for most drilling rig applications. Today's rapid expansion of deep water drilling activities, however, has created a need for significantly longer current measurement ranges.

There are two ways to achieve this increased range which we have considered. The first is the use of multiple ADCPs located at different depths such that each profiles a different portion of the water column. The second is the development of a longer range ADCP which operates at a lower frequency, 38 kHz, and which employs more versatile signal processing techniques.

The use of multiple ADCPs is conceptually simple but may be quite complex in practice. Among the difficulties involved are:

- the need to communicate data from great depths via electromagnetic or acoustic means,
- the potential for acoustic interference between ADCPs,
- the need for synchronization of the ping cycles, and
- the difficulty of relating data from multiple ADCPs to a common spatial and temporal frame of reference.

For these reasons, RDI has made the development of a 38 kHz ADCP for drilling rig applications a high priority. We considered extension of our conventional, four-beam technology to 38 kHz to be impractical because of the extremely large physical size and weight of such an instrument. Instead, we have used the well known principle of forming the four required beams from a single, multi-element planar array transducer by means of electronic beamforming. The result is a 38 kHz Phased Array ADCP which can profile to around 1000 meters but which is essentially the same size as our conventional four-beam 75 kHz systems.

One issue which affects both conventional and phased array ADCPs when used in drilling rig applications is acoustic reflection from objects in the water column. These objects include the drilling riser, tensioning cables, rig support structure, and other instruments suspended in the water column. If any of the transmitted beams intersects such an object, the reflection from it

can easily overwhelm the scattering from the small particles in the water which the ADCP uses to measure currents. The result can be a degradation of the current data in the depth range of the interfering object.

Different methods can be used to alleviate this problem with a conventional versus a phased array ADCP. With conventional systems, we must either carefully orient the ADCP so that the beams do not strike any submerged objects, or we must disable one of the beams. At least three beams must always be operational in order to get a complete solution for the currents. The difficulty with the orientation approach is that it can be undone by any changes in the positions of suspended objects. Electronically disabling a beam is not a designed-in feature of existing ADCPs.

The phased array ADCP has several potential advantages in solving this problem. First, by very careful manufacture of the array and beamformer, acoustic sidelobes can be minimized. In addition, different acoustic frequencies and/or different signal codes can be used on each transmitted beam to reduce cross coupling. Finally, enhancements to our beamformer are currently in the design phase which will permit us to easily suppress one transmit beam and to vary the orientation of the beams electronically. These capabilities will give greatly enhanced capabilities to avoid unwanted acoustic reflections without the need for reorienting the transducer. Dynamic Positioning (DP) rigs present major noise problem for the PA-38 ADCP. With large positioning thrusters running on a continuous bias the operating range of the system will be greatly reduced if certain installation techniques are not followed. What was found to be successful was a combination of moving the PA-38 ADCP into deeper water (200m), away from the thrusters (15m) and outfitting the transducer with an acoustic baffle "jacket" to suppress the surface noise from the back and sides of the transducer. The other major technique will be to operate the system in the Narrow Band mode (NB)

To better understand the whole acoustic noise environment on these types of rigs a field study was done in September of 1997. Fugro/GEOS installed a 38 kHz phased array ADCP on the drilling rig "Ocean Alliance". For various reasons, the profiling range was less than expected. Measurements of the acoustic noise environment were made in the water where the

ADCP was located by lowering a calibrated hydrophone, Model ITC6050C, from the platform. The noise signature of the oil rig was measured with the hydrophone located between 20m to 100m at 20m intervals. At each level, collected 10 data files at a 250 kHz sampling rate, and 10 data files at a 100 kHz sampling rate. 2 sets of data with 20 files for each set were collected.

The noise spectrum data was analyzed by performing an FFT on data collected after compensating for the known frequency response of the hydrophone. The following figures (Figs. 3,4,5) show the typical noise spectra collected at 20m, 40m, and 100m, respectively. The first figure is the spectrum at 250 kHz sampling data, the second one is for 100 kHz sampling, and the third one shows the noise spectrum from 25 kHz to 45 kHz.

The noise spectrum is generally flat for frequencies above 20 kHz. The noise level is strongest at 20m and 40m, near the thrusters located at 30m depth. It is reduced with increasing depths. At 100m, the noise level is about 15 dB below the levels at 20 & 40m.

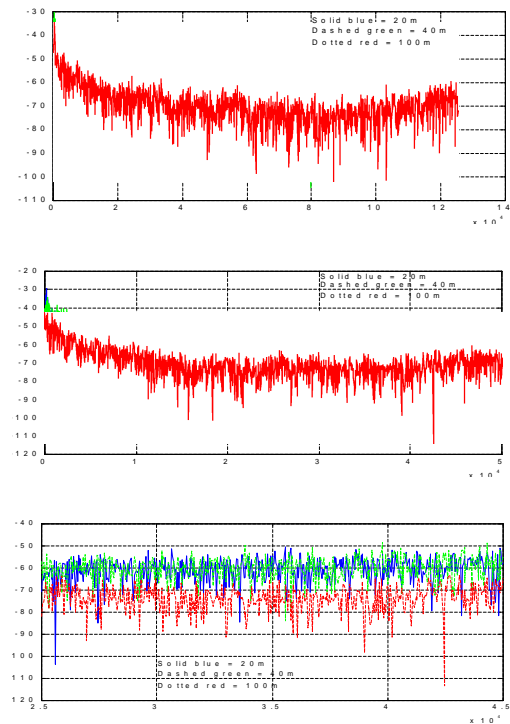


Fig. 3,4,5

The primary noise source is probably the thrusters, because the noise level decreases with

increasing depth -- 15 dB per 60m. The relatively flat noise spectrum suggests that 38 kHz is a desirable frequency for an ADCP on an oil rig. It had previously been suggested that the noise spectrum might drop by from 6 to 12 dB per octave in this spectral region. If so, this would tend to favor the 75 kHz systems. However, based on these measurements, it appears that this is not the case and that superior current profiling ranges can be achieved by a 38 kHz ADCP.

IV. DATA COLLECTION/PERFORMANCE

This data was collected from a rig in the Gulf of Mexico operated by Shell E & P Technology Company. (fig. 14)

The 38 kHz phased array transducer was deployed from the platform at an angle of about 15 degrees from the vertical. The raw data showed that beam 4 was invalid, possibly due to an underwater obstruction or other unknown reason. The beam 4 data, therefore, have been disregarded for the presented data analysis below.

Figures 6 and 7 show range and echo intensity data. The average echo intensity of beams 1 through 3 is plotted in Fig. 6 along the x-axis. The y-axis is the range in meters. The system was set up to collect 32 bins where every bin is 32 meters in size. Hence the plotted range reflects the total range that was selected and was not limited by system performance.

At approximately a range of 350 meters, the average scattering strength increases again by about 18 counts near a range of 500 meters. This increase is equivalently to about 8 dB. The cause of this change in volume scattering strength has not been investigated in this paper. Possible reasons are a concentration of zooplankton or perhaps the presence of a cloud of dredging material from the drilling operation.

Beyond a range of 500 meters the echo intensity decreases about as expected. Near a range of 950 meters the bottom echo is beginning to influence the signal. That is, that the bottom is fully illuminated within the next few bins.

The echo intensity is a measure of signal to noise ratio (S/N). In the BB-mode of operation

the S/N ratio that corresponds to a signal correlation threshold up to which the signal is considered acceptable is 0 dB; this relationship is shown in Eq. 1. This level is reached approximately at an echo intensity between 20 and 30 counts (This range of counts is according to RDI's experience. A more accurate measure can be obtained if the system is calibrated). Thus, the maximum range in this application was strictly limited by the system setup as it seems that there is at least a S/N ratio margin of 15 dB available.

$$\mathfrak{R} = \frac{b}{1+1/SNR} \quad (1)$$

where:

\mathfrak{R} : Correlation magnitude;

β : Decorrelation factor, for this purpose assumed to be 1;

SNR: Signal to noise ratio (linear form).

Fig. 7 shows the range vs. normalized signal correlation magnitude. It supports the claim that the maximum range was not yet reached. The correlation magnitude threshold is, by default, set to 50%. At a correlation of 50% the S/N ratio is about 0 dB. Fig. 7 shows that at a range of 1000 meters the correlation has just dropped to 96 – 97 %; which is still an exceptionally high correlation value at 1000 meters.

Therefore, the conclusion is that the range obtained for this installation is more than that given in the Ocean Surveyor's specification. However, it should be mentioned that this range is not achieved in all cases. One of the single most important environmental parameters in obtaining this range is volume scattering strength. Provided that the scattering level does not fall below about –95 to –98 dB and the sea state is near zero, the specified range should be obtainable in most cases. Other equally important factors are ambient noise caused by sources such as thruster-generated noise (propeller noise) and other mechanical noise.

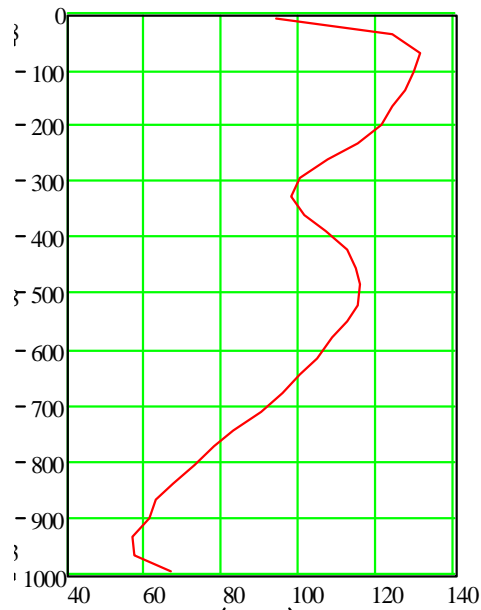


Fig. 6 (Above):(Vertical axis-meters) Range in meters vs. average echo intensity in counts of Beam 1 through 3. A count equals about 0.42 dB in change of intensity. A significant change in scattering strength can be observed between a range of 200 to 500 m. Near a range of 950 m, the bottom reflection becomes apparent.

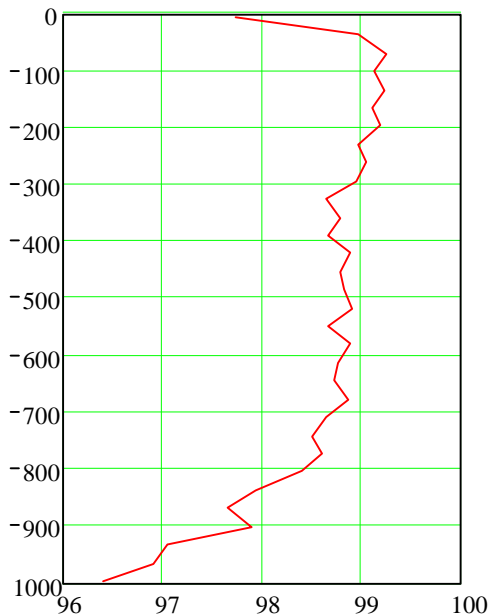


Fig. 7(Above): (Vertical axis-meters) Range in meters vs. normalized correlation magnitude in percent. The graph shows that the typical correlation threshold of 50% as required for the velocity measurement to be considered valid has

not been reached yet.

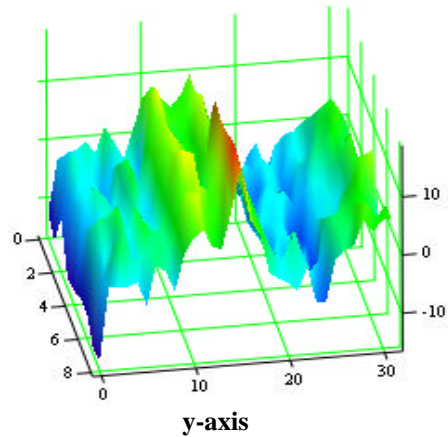


Fig. 8(Above): Easterly velocity surface plot. One ensemble consists of 150 pings. The x-axis shows the ensemble (0-8) number (time), the y-axis the range in bins, where the bin size is 32 meters, and the z-axis shows the velocity in cm/s.

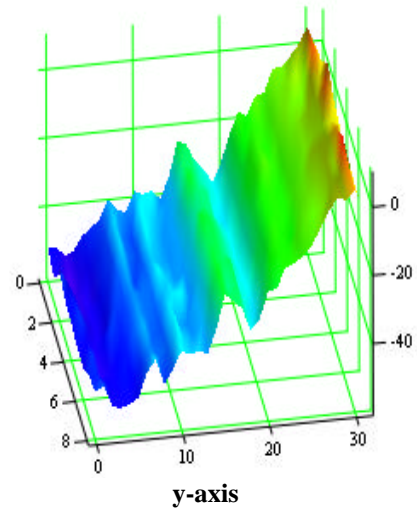


Fig. 9(Above): Northerly velocity surface plot. One ensemble consists of 150 pings. The x-axis shows the ensemble (0-8) number (time), the y-axis the range in bins, where the bin size is 32 meters, and the z-axis shows the velocity in cm/s.

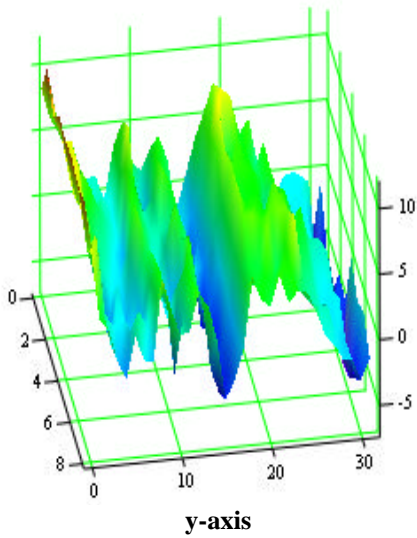


Fig. 10(Above): Vertical velocity surface plot. One ensemble consists of 150 pings. The x-axis shows the ensemble (0-8) number (time), the y-axis the range in bins, where the bin size is 32 meters, and the z-axis shows the velocity in cm/s.

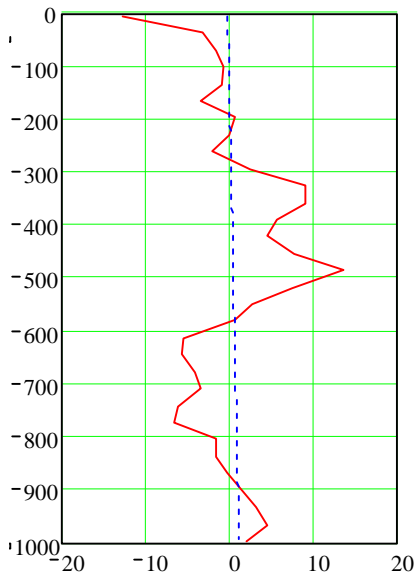


Fig. 11(Above): (Vertical axis-meters) The solid line is the range in meters vs. easterly average velocity profile in cm/s. The dashed line is linear best fit to the profile. The profile consists of 1350 pings. It is worth mentioning the fact that the velocity is near zero at the bottom.

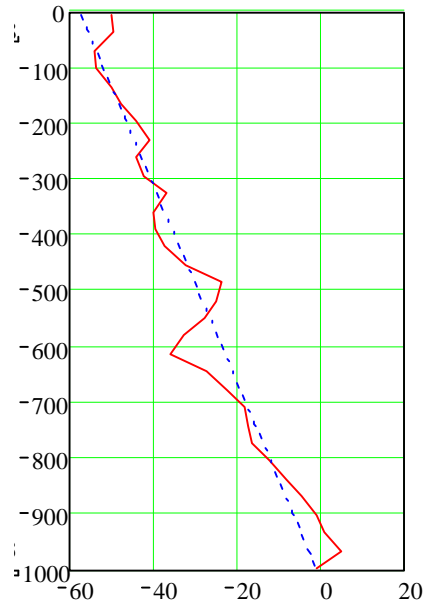


Fig. 12(Above): (Vertical axis-meters) The solid line is the range in meters vs. northerly average velocity profile in cm/s. The dashed line is the linear best fit to the profile. The profile consists of 1350 pings. The slope of the linear fit is 0.06 cm/s-m. It is worth mentioning the fact that the velocity is about zero at the bottom.

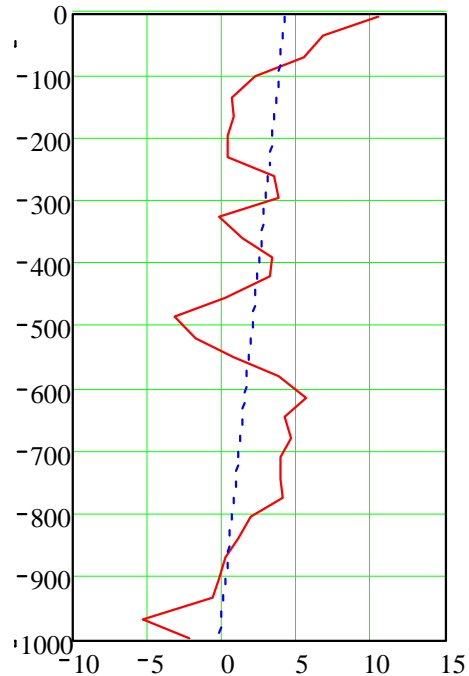


Fig. 13: (Above): (Vertical axis-meters) The solid line is the range in meters vs. vertical average velocity profile in cm/s. The dashed line is the linear best fit to the profile. The profile

consists of 1350 pings. The slope of the linear fit is 0.004 cm/s-m. It is worth mentioning the fact that the velocity is near zero at the bottom.



Fig. 14: deployment of the PA-38 ADCP that was used to collect the data presented in this paper, Shell E & P Technology Company.

V. SOFTWARE

Fugro/GEOS' RIGADCP software package provides the user with a series of readily interpreted graphical views of the measured data. The instantaneous profile plot, shown in Fig. 15, illustrates measured current speed and direction in each depth cell. It also provides a clear, numerical display of the maximum current speed through the water column. This screen is of particular interest to ROV operators. Other screen options include short-term and long-term time series displays at selected depths.

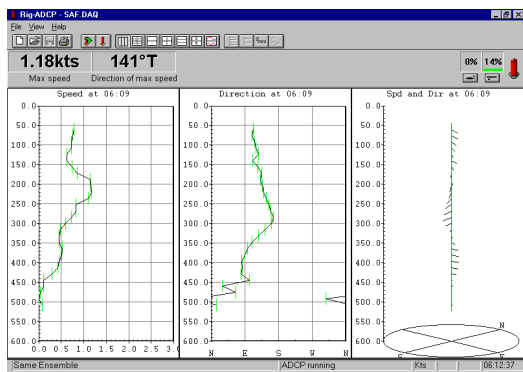


Fig. 15

Data Analysis and Presentation

Unlike conventional current meters which provide speed and direction time series for a discrete height above the bed ADCPs provide a significantly more comprehensive data set, including time series of current profiles and additional parameters, such as vertical velocity. To allow effective use of this data it has been necessary to develop a number of custom presentations and analysis techniques for the

data.

Data from the ADCPs is written in a rigorously applied database format; this is essential for quality control of the data. The ADCP provides a great deal of data on instrument performance including echo amplitude and percentage good pings for Narrowband ADCPs and correlation coefficient for BroadBand units. To allow determination of the quality of the data, it is essential that these data are reviewed. To allow this, color contour plots of these parameters are printed and assessed.

On completion of the QC of the data set, a number of data analyses and presentations are produced in addition to standard presentation produced for current meters. The following are produced:

- Color contour plots of orthogonal velocity and vertical velocity.
- Analysis of the data to derive extreme profiles and percentiles, which are subsequently presented in profile form.
- Operational window analysis, this involves the persistence analysis of profile data, this can be used, for example, to assess the likelihood of period of vortex induced vibration (VIV) on riser string to be determined.
- Rotary Spectral analysis, allowing summary of flow properties through depth.

Preparing such types of presentation greatly increases the value of the ADCP data, and allows the reader to understand quickly and accurately the water column characteristics.

Current Forecasting

The foregoing text describes systems for the provision of measured current data. During years of measurement and operation in deep-water regions, the complexities and extreme variability of current conditions have become apparent. What is often required offshore, to assist in operational planning, is not knowledge of what the current velocity is now, but how it is likely to develop over the next few hours. Currents in the region regularly exceed 1 meter per second (2 knots) and many operations can only be performed successfully below a particular current speed threshold (such as ROV deployment, riser deployment and recovery, 'spudding in', ship loading etc.). The costs of suspended operation during unfavorable current conditions can be extremely high; equally, major

damage may occur if current-sensitive operations are commenced without due regard to the forthcoming flow development.

It is unlikely that a specialist oceanographer will be present offshore to interpret recent current measurements and assist in operational decision-making. In the more complex flow patterns which occur on the continental shelf edge, it is difficult for non-oceanographers to interpret recent measurements and to anticipate what is likely to happen more than one or two hours ahead.

Fugro/GEOS has developed a short-term current forecasting system, ADCPPRED, which can be used to predict current speed and direction, through depth, over the forthcoming 24-hour period. ADCPPRED is a PC-based software package that is used in combination with RIGADCP.

Extensive numerical analysis was undertaken on previously measured deep-water current profile data. Harmonic analysis was used to determine the predictable tidal component of flow, and then empirical pattern-recognition techniques were developed to estimate the highly variable non-tidal component of flow. The non-tidal flow comprises a persistent north-easterly ocean current component, intermittent passage of eddies and various high-frequency effects. The approach taken with ADCPPRED was to provide a robust empirical prediction procedure rather than to attempt a full hydrodynamic interpretation of the available data. During the development phase, various prediction algorithms were tested on past data to assess how well they would have performed in real-time. The preferred scheme was then encoded into a real-time software application.



Fig. 16

RIGADCP provides the user with an easily interpreted graphical display (fig.16) showing time series at two selected depths through the water column. To the left of the centerline, current speeds measured over the last 24 hours are shown, together with past predictions that were made N-hours before each measured data point. The N-value is selected by the user. Comparison between measurements and past predictions provides an indication of how well the prediction scheme is working at the present moment in time. To the right of the centerline, predicted current for the next 24-hour period is displayed. This is shown for the predictable tidal component (faint line) and also for the total current (heavy line) which also includes all the variable non-tidal effects.

The current prediction software has now been operational offshore for more than 2 years. Since its initial installation, various refinements have been made to improve the quality of the forecast and to optimize the form in which the information is displayed to the decision-maker.(fig. 17)

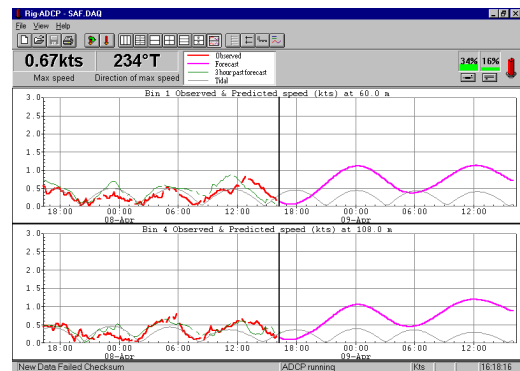


Fig. 17

ADCPPRED now provides an effective tool to support operational planning offshore and will continue to be developed and refined by Fugro/GEOS.

VI. CONCLUSION

The development of deep water current measurements from rig environments have been made possible by the close collaboration between an expert user; Shell E & P Technology Company, an experienced system integrator; Fugro/GEOS and a instrument manufacturer; RD Instruments.

The PA-38 ADCP with the ability to profile currents over 1000m has shown how it could be successfully deployed and integrated into the complex operations of different types of mobile rig environments. The benefits of real time current data has been found to be essential in the support of many rig operations.

A great amount of progress has been made over many years to establish this system as a proven commercial product. The work will continue as we learn from the experiences of the end users. As a development team we have a continuous commitment to refine our processes, data collection and viewing software and the current meter itself to meet the future requirements of the oil and gas industry.

ACKNOWLEDGMENTS

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