SEA TRIALS OF A LOWERED, THREE-AXIS CURRENT METER

K. Saunders, H. Perkins, L. Banchero, S. Sova 1 and J. Vega 2

1) Naval Ocean Research and Development Activity, NSTL Station, MS 39529
2) Computer Sciences Corporation, NSTL Station, MS 39529

ABSTRACT

Results of sea trials for a prototype over-the-side three-axis current meter/CTD are reported. The instrument is novel in that it measures three components of velocity, of acceleration and of magnetometric field, thus enabling conversion of the measured velocity into earth coordinates. Suitable processing of the accelerometer data also permits the measured velocity to be corrected for short-period instrument motions induced by the ship. The tests reported here indicate that the technique can measure currents relative to the mean ship drift with an error of order 1 cm/sec in a variety of sea states.

1. DESCRIPTION OF INSTRUMENT

An attended profiling instrument has been developed which measures three independent components of water velocity relative to the instrument, three components of the earth’s magnetic field, and three components of acceleration in addition to the usual CTD parameters of conductivity, pressure and temperature. The current components are obtained by acoustic doppler methods, as described in Lawson et al. (1). The geometry of the acoustic paths and the results of towing calibration tests have been presented by Perkins, et al. (2).

In operation, the magnetometer and accelerometer data can be used to determine the linear transformation which converts current components from the instrument coordinates in which they are measured into geomagnetic coordinates. In this paper, it is assumed that the instrument acceleration is entirely vertical; that is, that the accelerations induced through the motion of the ship are very nearly in the direction of gravity. Under this approximation, the horizontal acceleration of the instrument is identically zero and so corrections to the current for instrument acceleration can only be made in the vertical velocity component. The quality of this approximation was monitored by noting variations in the angle between the observed total acceleration and magnetic vectors, i.e., the apparent magnetic dip. This angle rarely varied by as much as 20° and usually by less than 10° r.m.s.

A more complete analysis of the problem, in which the assumption of purely vertical acceleration is not made, is possible and indicates that velocity corrections for horizontal accelerations can be made under certain conditions. The algorithms for doing this are now being implemented and will be reported at a later time.

The data gathering and display system is represented in Fig. 1. The signal from the underwater unit is transmitted in bit-serial FSK code via a standard CTD cable and winch to the deck unit, each channel of data being transmitted 15 times per second. An HP-9825 calculator acts as controller of a byte-serial bus, routing the data to a 9-track tape for primary data logging. The calculator also periodically samples the bus, processes a scan of data and transmits the result for display in.

Figure 1. System used for data collection and real-time processing and display.

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any of several selectable formats to the three display devices for listing or plotting. Many aspects of the cast can thus be monitored in real time, although motion compensation must presently be done off-line due to the limited speed of the calculator.

2. DESCRIPTION OF SEA TRIALS

A series of instrument deployments were made for test and evaluation purposes during November, 1980, in the southwestern Gulf of Mexico near 23°N 94°W. During these tests, two basic deployment methods were evaluated; a direct lowering approach, as with a CTD cast, and a tethered arrangement in which the instrument was suspended from a float, the depth of which could be controlled by the size of the catenary of wire between the float and the ship. A schematic summary of the last five of the seven casts which were made is given in Fig. 2.

During the tests, a vane was attached to the instrument for streamlining and to eliminate wobble caused by vortex shedding from the pressure case. The vane was made of two sheets of polycarbonate plastic held tangent to each side of the cylindrical pressure case and fastened together at the trailing edge. Being open at top and bottom, the vane was easily flushed by vertical currents and so was of low effective mass when moved up and down, thereby minimizing instrument pitching motions.

![Figure 2](image)

Figure 2. Schematic of the deployment configuration used in each of the seven casts.

### TABLE 1. SUMMARY OF OPERATIONS

<table>
<thead>
<tr>
<th>CAST NO.</th>
<th>DATE, NOV '80</th>
<th>WINDS (kts)</th>
<th>WAVES (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1, 2, 3</td>
<td>15 16 17</td>
<td>7 0 24 32</td>
<td>3 12 14</td>
</tr>
<tr>
<td>4, 5</td>
<td>18 19 20</td>
<td>32 18 22</td>
<td>14 10 10</td>
</tr>
<tr>
<td>6</td>
<td>21</td>
<td>25</td>
<td>7</td>
</tr>
</tbody>
</table>

The first two casts were devoted to vane evaluation and other initial problems and so are not discussed further. Because of a continuing technical problem, the first six casts were with the instrument at a nominally constant depth; only during cast seven was the instrument repeatedly raised and lowered through the water column.

Wind and sea conditions during each of the casts are given in the Table. Passage of the late Hurricane Jeanne and an early cold front a few days later gave ample opportunity to evaluate the effectiveness of the procedure for correcting for instrument motion in moderately severe seas. Work was suspended during Nov. 16 and 18 due to heavy weather.

3. SUMMARY OF RESULTS

Figures 3 through 5 show short sections of vertical velocities under various conditions before and after correction based on the integrated vertical acceleration. The ship-induced motion, which is so prominent in the uncorrected velocity, is virtually eliminated except in cast 6 (Fig. 5). The residual linear trend is an artifact of the correction procedure and will be eliminated in a more sophisticated treatment.

A more complete description of the instrument motion is contained in the spectral presentations of Figs. 6 to 9. The three curves labeled 1, 2 and 3 in each figure correspond respectively to acceleration normal to the instrument axis and in the plane of the vane, normal to both the axis and the vane, and along the instrument axis, which is nominally vertical. Note that these accelerations are in the natural coordinates of the instrument and have not been transformed into geomagnetic coordinates. The spectra, given on log-log scales, were computed by standard methods and have about 15 degrees of freedom.

Figure 6 is from a direct lowering in calm seas and shows the expected result that the axial component of motion is highly dominant. The major peak is at about 7 seconds and corresponds to ship roll, while the secondary peak is at about 3.5 seconds and probably is primarily due to ship pitch, although harmonics of the main peak may contribute to it. The spectrum of fore-and-aft motion (trace 1) is similar to that of axial motion, but is smaller by over three orders of magnitude in spectral level, or about a factor of 50 in amplitude.
Figure 3. Vertical component of velocity before and after correction for instrument acceleration during a short portion of Cast 3.

Trace 2 is smaller yet by a factor of 6 in amplitude, presumably because the vane inhibits the corresponding component of motion.

Casts 5 and 6, in which the profiler was suspended from a buoyant, tethered package were experiments to mechanically decouple the instrument from ship motion. Results from the first of these, given in Fig. 7, shows some reduction in axial motion relative to cast 3 in spite of much higher seas. The large increase in horizontal motion is attributed to the "water pulley" effect, familiar to those who deploy arrays in an anchor last mode. This effect arises because the longitudinal drag coefficient of a cable is about 100 times smaller than the transverse drag coefficient (3). Hence, there is greater resistance of the cable to transverse motions than to longitudinal motions - in effect the water acts as a tube through which the cable may be moved parallel to itself with little resistance.

For cast 6, a string of glass spheres attached to a chain supported the profiler. The CTD cable was attached to the uppermost section of the chain which was buoyed with small glass floats to increase the compliance at that point. The modified design resulted in a decrease in amplitude of the vertical motion by about a factor of three (Fig. 8), a much greater reduction than can be attributed to the lesser seas. The corresponding increase in horizontal motions (traces 1 and 2) may indicate a pendulous motion of the float-instrument-weight system.

Figure 4. As in Fig. 3, but for Cast 5.

Figure 5. As in Fig. 3, but for Cast 6.

The final lowering, cast 7, was again a direct lowering as was cast 3, but it differs from cast 3 in two respects: the instrument was used in a profiling mode, being raised and lowered by the CTD winch, and high winds made it necessary to maintain steerage way using the main engines in order to keep the bow into the weather. The large vertical accelerations seen in Fig. 9 are as expected, and the fore-and-aft
horizontal motions (trace 1) are again about a factor of 50 lower in amplitude. The source of the relative increase in transverse motion (trace 2) is not clear.

Figure 6. Spectra of instrument acceleration based on components in instrument coordinates for Cast 3. The components 1, 2 and 3 correspond respectively to straight ahead, sideways and up-down components, as described in the text.

Figure 7. As in Fig. 6, but for Cast 5.

Figure 8. As in Fig. 6, but for Cast 6.

Figure 9. As in Fig. 6, but for Cast 7.

4. CONCLUSIONS

A profiling current meter capable of measuring three components of current has been evaluated at sea. The three components of acceleration and of magnetic field sensed by the instrument determine the orientation of the instrument in space and provide the information required to transform the measured current components into geomagnetic coordinates.
Further, if the instrument acceleration is predominantly vertical, as is especially true if the instrument is simply lowered from the ship, then the acceleration data may be used to correct the unmeasured vertical component of current for variation in instrument motion. The corrected vertical velocity has errors of order 1 cm/sec or less, even in moderately high seas.

Deploying the instrument from a subsurface float which is connected to the ship by a large catenary of conducting wire can significantly decrease vertical acceleration, but at the expense of increased horizontal acceleration. A technique for making velocity corrections based on these horizontal accelerations is under evaluation.

The instrument appears adequate with either deployment method to resolve currents associated with overturning events in the ocean.

5. REFERENCES