



The EM-POGO: A simple, absolute velocity profiler

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ABSTRACT

Electromagnetic current instrumentation has been added to the Bathymetry Systems, Inc. POGO transport sondes to produce a free-falling absolute velocity profiler called EM-POGO. The POGO is a free-fall profiler that measures a depth-averaged velocity using GPS fixes at the beginning and end of a round trip to the ocean floor (or a preset depth). The EM-POGO adds a velocity profile determined from measurements of motionally induced electric fields generated by the ocean current moving through the vertical component of the Earth's magnetic field. In addition to providing information about the vertical structure of the velocity, the depth-dependent measurements improve transport measurements by correcting for the non-constant fall-rate. Neglecting the variable fall rate results in errors $O(1 \text{ cm s}^{-1})$. The transition from POGO to EM-POGO included electrically isolating the POGO and electric-field-measuring circuits, installing a functional GPS receiver, finding a pressure case that provided an optimal balance among crush-depth, price and size, and incorporating the electrodes, electrode collar, and the circuitry required for the electric field measurement. The first EM-POGO sea-trial was in July 1999. In August 2006 a refurbished EM-POGO collected 15 absolute velocity profiles; relative and absolute velocity uncertainty was $\sim 1 \text{ cm s}^{-1}$ and $0.5\text{--}5 \text{ cm s}^{-1}$, respectively, at a vertical resolution of 25 m. Absolute velocity from the EM-POGO compared to shipboard ADCP measurements differed by $\sim 1\text{--}2 \text{ cm s}^{-1}$, comparable to the uncertainty in absolute velocity from the ADCP. The EM-POGO is thus a low-cost, easy to deploy and recover, and accurate velocity profiler.

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1. Introduction

Vertical profiles of ocean currents are essential to studies of depth-dependent physical processes in the ocean such as internal waves (including near-inertial waves, internal tides, and the broadband spectrum), bottom boundary layers, western boundary currents, mid-depth jets, mesoscale eddies, high-latitude overflows, and the energy cascade from internal waves to shear and mixing. Since initial attempts to measure velocity profiles with mechanical current meters proved largely unsatisfactory, a variety of alternative techniques have been used, including acoustically tracked dropsondes (Pegasus, TOPS) (Hayes et al., 1984; Luyten et al., 1982; Spain et al., 1981), acoustic travel-time (MMP) (Doherty et al., 1999) and Doppler shift (lowered ADCP) sensors, and motional induction (XCP, AVP, and EM-APEX) (Sanford et al., 1985, 2005). Each technique and instrument has different strengths and weaknesses, including water column coverage, ease

of use, vertical resolution, sensor suites, and cost. Here we report on an instrument development at the “shoestring” end of the spectrum, highlighting the potential for a self-contained device, able to be deployed by only two people from a small ship, requiring little design cost and using inexpensive components (approximately \$5000 in total). The result was the EM-POGO, a cost-effective, easy to deploy and recover, free-falling absolute velocity profiler with $< 25 \text{ m}$ vertical resolution.

The concept for the EM-POGO grew from persistent enthusiasm by Tom Rossby about the inclusion of motional induction sensors (Sanford, 1971; Sanford et al., 1978) in his POGO transport floats (Rossby et al., 1991). This would add value by measuring of the distribution of ocean velocity along the trajectory of the POGO. Furthermore, the combination of the transport meter and the electric field (EF) measurements allows for absolute velocity profiles. Ultimately, Rossby obtained NSF funding to do this and engaged our (Sanford's) group at APL-UW to implement this capability.

The development process, theory, and scientific results to date are described in the following sections: Section 2 describes the design and implementation process. The theory of how the EF measurements, obtained as electrode voltages, are interpreted as velocity is briefly discussed in Section 3. Sea-trials presented in Section 4 confirm that the EM-POGO is able to provide accurate

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absolute velocity profiles data with at least 25 m vertical resolution, relative velocity with standard errors of $<1 \text{ cm s}^{-1}$ and absolute velocities with a standard deviation of $0.5\text{--}5 \text{ cm s}^{-1}$.

2. Materials and methods

In order to preserve electrical isolation (to minimize noise sources) and conserve design costs, it was decided to add the EF measurement by simply inserting the electronics from the EFF (a RAFOS float with EF measurement capabilities) (Rossby et al., 1986; Sanford et al., 1995) into the POGO tube as a completely separate system. The POGO technique, based on the primitive free-falling transport float developed and used by Richardson and Schmitz (1965), has been updated over the years, including the additions of an acoustic pinger for tracking capabilities, a VHF beacon and a xenon flasher to aid recovery, and a new instrument housing. The POGO was designed to free-fall at a constant rate to a pre-determined depth, release drop-weights, and return to the surface at a constant rate providing a straightforward measure of horizontal distance, based on shipboard Loran C readings at the release and recovery times, traveled over time. A temperature profile was also recorded along the trajectory. This method assumes a constant fall/rise rate, which is discussed in Section 3. The POGO was used successfully as a transport meter in numerous experiments (Meinen and Clarke, 2000; Pickart and Lindstrom, 1994; Rossby et al., 1991) with an uncertainty of $\pm 0.02 \text{ m s}^{-1}$. GPS was a later addition to the POGO to improve the instrument's ability to determine the start and end positions of the profile. More details of the POGO design and components including tracking and recovery devices and the original POGO circuitry board are discussed in Rossby et al. (1991). Similarly, a more in-depth review of the EFF can be found in Sanford et al. (1995), Szuts (2004) and Szuts and Sanford (2013).

Features and components of the EM-POGO that are new or modified from the POGO or EFF are described below. Mid-way through the development, it became apparent that a new tube had to be selected to fit the wide EFF circuit board. A 2-m long cylindrical glass tube with an aluminum endplate (Fig. 1) was constructed (Schott Tubing) with an outer diameter of 11 cm, a wall thickness of 7 mm, a weight of 23.2 lb in air, a buoyancy of 12.3 lb in seawater, and a crush depth of 3324 m, and the hemispherical end was hand-shaped by a glass blower. The temperature sensor, electrode connectors, and the acoustic pinger connectors run through the endplate. The addition of these connectors limits the profiling depth by decreasing the endplate pressure rating to less than 2000 m.

The instrument profiles (Fig. 2) by changing its buoyancy from negative to positive upon approaching the bottom or a preset pressure level (when operating with a mid-depth pressure release) by dropping weights hung 5 m below the glass tube. A 12-h back-up corrosion link is also attached between the bottom-release and drop-weight in case the release mechanism fails. The amount of drop-weight is chosen to facilitate an equal fall and rise rate and good vertical resolution. The 5 m of line allows the instrument to decelerate without hitting the bottom. In the 2006 sea trial (Section 4.2), the rise and fall rates were $\sim 1.5 \text{ m s}^{-1}$ and the vertical resolution was 25 m. The instrument rotates as it falls and rises to prevent kiting and to modulate the electrode voltage signal. This modulation is necessary because the ocean induced electric field is very small, $O(1\text{--}10 \text{ } \mu\text{V/m})$ relative to the temperature ($350 \text{ } \mu\text{V/}^\circ\text{C}$) and salinity coefficients ($500 \text{ } \mu\text{V/PSU}$) of the electrodes. The electrodes are encased in agar made with seawater, to form an electrically conductive seaweed gel, to slow heat and salt transfer to the electrode surfaces. With the EM-POGO electrode separation of 0.14 m, electrode voltages are

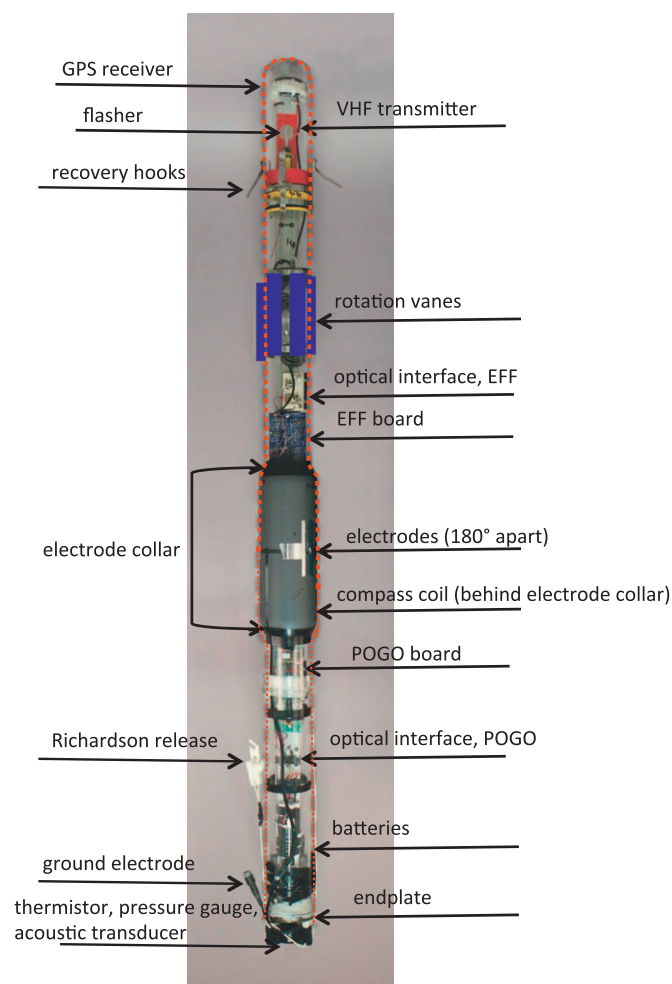


Fig. 1. A photograph of the EM-POGO with the major components labeled. The drop weights, optional pressure release, and corrosion links are not shown. The electrodes are covered by silver tape to prevent desiccation. The glass hull is outlined by a dashed red line. (For interpretation of the references to color in this figure caption, the reader is referred to the web version of this article.)

$O(1 \text{ } \mu\text{V})$. The vertical resolution can be increased by fitting the data over fewer instrument rotations or increasing the rotation rate. Here, four rotations were used, as this time interval smoothed over much of the noise (Fig. 3).

The POGO and the EF components remain completely isolated both physically and electrically on the combined instrument (Fig. 4). The POGO board uses Bathymetry Systems, Inc. firmware and stores the pressure and temperature data. It also controls the pinger, flasher, and radio transmitter. The EF board stores the electrode and compass voltages and GPS data. A Garmin GPS 16 is used on the EM-POGO; it has wide area augmentation system (WAAS) differential GPS capabilities with a position error of less than 3 m 95% of the time. This small error is crucial for obtaining an accurate measure of the barotropic velocity component. The software on the EF board was amended to receive and store the necessary GPS data.

Isolating the POGO and EF electronics is more cost-effective than a redesigned, smaller circuit board for the EF measurements, or a combined EF and POGO board. Separate magnetic reed switches turn the POGO board and the EF board on and off, and separate optical links are used to offload the data through the glass hull. The POGO data offloads at 1200 baud and the EF data at 9600 baud. No onboard computation is performed. MATLAB software has been written for post-processing and is available to potential users on request.

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