New Buoyancy Engine for Autonomous Vehicles Observing Deeper Oceans

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ABSTRACT
Buoyancy engines are key components used in profiling floats and other devices that observe the upper part of the world’s oceans. We have proposed and developed a new buoyancy engine for autonomous marine vehicles. It has a reciprocating piston and a three-way valve and can function at pressures as high as 35 MPa (3500 dbar). Use of the new buoyancy engine can increase the observation depth from the 2000 m capability of existing floats to deeper than 3000 m. Laboratory tests verified its good energy efficiency and endurance.

KEY WORDS: Buoyancy engine; Argo; profiling float; glider; virtual mooring; deep ocean observations

INTRODUCTION
In recent years, development of autonomous marine vehicles such as profiling floats (Davis et al., 2001; Roemmich et al., 2004; Gould, 2005) and gliders (Rudnick et al., 2004) has accelerated rapidly. Argo (Argo Science Team, 2001), which is a worldwide observation system using profiling floats, has brought revolutionary progress in oceanography. Argo is an international program launched in 2000 to observe the upper part of oceans around the world using a network of numerous profiling floats deployed at every 3 deg of latitude and longitude.

The floats control their depth merely by changing their volume (i.e. buoyancy) using buoyancy engines. For four years or longer, they drift independently at a preset depth and then rise to the sea surface every 10 days. Oceanic profiles of temperature and salinity are observed during a float’s ascent. The data are transmitted to stations on land via satellites while the float is on the sea surface. The Argo observation network of 3000 floats was completed in 2007 (Roemmmich et al., 2009). Now more than 100,000 profiles of temperature and salinity are obtained from the whole ocean every year. All data become available within 24 hr after float observations, supporting nearly real-time monitoring of the interior of the world’s oceans. The huge amounts of oceanic data provided by Argo have brought great progress in oceanic and climatological sciences (Freeland et al., 2010).

Profiling floats of the present types can submerge to a depth of 2000 m (corresponding to 2000 dbar, i.e. 20 MPa, in pressure), which means that ocean observations by Argo are limited to 2000 m. Because the average depth of the ocean is 3800 m, only the upper half of the ocean can be examined by Argo using present technologies. Consequently, ocean observations in the deeper half are few. Even now, deeper observations must be conducted by research ships as they were done before the advent of the profiling floats. Results of many recent studies of global warming and climate change strongly support the value of ocean observations beyond 2000 m depth (Garzoli et al., 2010). Measurements at greater depths are indispensable for precise estimation of the increases in oceanic heat storage and the sea level rise derived from seawater expansion caused by its warming (e.g., Levitus et al., 2005; 2009; Intergovernmental Panel on Climate Change, 2007).

To produce profiling floats that can observe ocean depths greater than 2000 m, reliable buoyancy engines must be developed. They should be small and light, and must function at great depths using little energy. Buoyancy engines of the present profiling floats used in Argo are roughly of three types. The first is an engine with a single-stroke piston driven by a ball screw (Davis et al., 2001). In an engine of this type, the piston injects (extracts) hydraulic oil stored in a long cylinder to inflate (deflate) a bladder placed outside of the float hull; the hydraulic oil moves bidirectionally in the whole hydraulic circuit. This engine is most familiarly used in existing floats such as the Sounding Oceanographic Lagrangian Observer (SOLO) developed by Scripps Institution of Oceanography and Woods Hole Oceanographic Institution (United States), Autonomous Profiling Explorer (APEX) by Teledyne Webb Research (United States), and Navigating European Marine Observer (NEMO) by OPTIMARE (Germany). The second is an engine with a metallic plunger, as used in the New Profiling float in Japan (NINJA, Tsurumi Seiki Co., Ltd.). This is a similar system to the single-stroke piston: the metallic plunger is pushed out to the water directly to control the float’s buoyancy. The third one is an engine with a high-pressure hydraulic pump (Davis et al., 1992). The external bladder is inflated by export of hydraulic oil through the operation of the high-pressure engine; it is deflated by release of a valve of the hydraulic circuit, by which the oil returns to an internal reservoir because of the pressure difference between the external bladder and the internal reservoir. The engine is also characterized by its one-way oil