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ScienceDirect
Deep-Sea Research I 55 (2008) 571–586
DEEP-SEA RESEARCH PART I
www.elsevier.com/locate/dsri

Instruments and Methods

Evaluation of the fall rates of the present and developmental XCTDs

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Received 26 February 2007; received in revised form 21 December 2007; accepted 26 December 2007
Available online 2 February 2008

Abstract

The fall rates of the current types of expendable conductivity-temperature-depth (XCTD) profilers and one under development are evaluated based on a series of co-located measurements with conventional conductivity-temperature-depth (CTD) profilers in the North Pacific. The types of probes investigated are the XCTD-1, the XCTD-2, the XCTD-3, and the XCTD-5 manufactured by Tsurumi Seiki Co., Ltd. It is confirmed that the present manufacturer's fall-rate coefficients for the XCTD-1/2 satisfy the accuracy guarantee of 2% of depth, at depth greater than 20 m. The coefficients of all XCTD types tested are dependent on water temperature, and the probes tend to fall slightly faster in warmer water. New sets of coefficients are given for the individual types, in a form that includes a correction for water temperature. It is also found that the ring hood structure of the XCTD-1/2 is effective in stabilizing the fall rates. The newer XCTD-3/5, which lack the hood, show larger scatter in the fall rate and occasionally violates the guaranteed depth accuracy.

Keywords: XCTD; Expendable conductivity-temperature-depth profiler; Fall-rate equation; Temperature measurement; Salinity measurement; VOS monitoring

1. Introduction

The expendable conductivity-temperature-depth profiler (XCTD) is a free-fall instrument for measuring the temperature and salinity profiles of the upper ocean. The development of the instrument was initiated during the 1970s independently by two companies, Sippican Inc., USA, and Tsurumi Seiki Co., Ltd. (TSK), Japan. After a number of improvements in the sensor unit and the probe body, the two companies individually started selling their own products by the mid-1990s (Lancaster, 1988; TSK, unpublished manuscript).

The Sippican XCTDs and the TSK XCTDs are different in many aspects. The year-to-year status of the instrument under development is given in the activity report (IOC, 1995, 1997) of the Integrated Global Ocean Services System (IGOSS) Task Team for Quality Control of Automated Systems

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0967-0637/$ - see front matter
doi:10.1016/j.dsr.2007.12.011

(TT/QCAS). Numerous studies to evaluate the XCTDs were conducted in the sea by the two companies and independent oceanographers using the probes from one company or the other (e.g. Hallock and Teague, 1990; Sy, 1993, 1996, 1998; Johnson, 1995; Mizuno et al., 1995; Albèrola et al., 1996; Mizuno and Watanabe, 1998; Gilson et al., 2000; Watanabe and Sekimoto, 2002; TSK, unpublished manuscript). Eventually, the two companies held a field test to compare overall performance of their XCTDs, and they agreed to supply only TSK XCTDs in the world market from 1999.

Because the XCTD probes carry no pressure sensors, an equation is needed to estimate depth from the time elapsed after the probe hits the water surface. The equation, variously referred to as a time-depth conversion equation, a fall-rate equation, or a depth formula, generally takes the following quadratic form:

$$d(t) = at - bt^2, \tag{1}$$

where $d(t)$ is the depth in meters at elapsed time, t, in seconds. The equation contains two empirical coefficients, a and b. The second term is included to represent the deceleration due to the loss of probe weight as the wire is spooled out. Therefore, the two coefficients should be positive when $d(t)$ is taken to be positive downward.

The primary specifications of the TSK XCTDs evaluated in this article are presented in Table 1. Currently available in the market are the XCTD-1, the XCTD-2, and the XCTD-3. The XCTD-2F has been sold only to the Japan Coast Guard. TSK has been developing a new type, temporally named as the XCTD-5, which would enable deep temperature/salinity profiling from fast-cruising vessels. Crucial for the size of the two coefficients, a and b, are total weight of probe, profiling range (i.e. length of probe wire), diameter (i.e. line density) of wire, and the form of the probe body.

The only difference between the XCTD-2 and the XCTD-2F is that the latter has longer canister wire, which makes the latter available on a faster platform. All the other dimensions are identical, as are the probe weights and hence the expected fall rates.

The thickness of the wire has been changed twice in the development of the TSK XCTD family. The first change occurred when the company developed the XCTD-2, with a profiling range (1850 m) longer than that of the already existed XCTD-1 (1000 m). The second change was made to obtain higher signal transfer rate in the development of the XCTD-3/5.

The XCTD-1, the XCTD-2, and the XCTD-2F have the same outer shape of probe. They have a ring hood at the end of the after-body (top of Fig. 1) for stabilizing the attitude of the probe as it descends. In contrast, the hood is not attached to the XCTD-3/5 (bottom of Fig. 1), which consequently have higher falling rates than the XCTD-1/2.

The change in probe shape and the second change in diameter of the wire enabled quicker measurement on faster vessels while not changing the length of the canister and hence the design of the launching unit. On the other hand, whether and how the hood-free structure of the newer two types affects the stability of their fall rate are not well known, and are points of concern in the present investigation.

The fall rates of TSK XCTDs have been estimated by several studies in the past. Originally, TSK obtained a set of coefficients for the XCTD-1 (simply called "XCTD" at that time) based on its own comparison with CTD profiles at sea (TSK, unpublished manuscript). Mizuno and Watanabe

Table 1
Specifications of the TSK XCTDs that are currently available or under development

Model	Speed (kt)	Range (m)	Probe weight (g)	Wire length (m)	Wire diameter (mm)	Ring hood	Manufacturer's a	Manufacturer's b
XCTD-1	12	1000	688	1025	0.09	Yes	3.42543	4.7×10^{-4}
XCTD-2	3.5	1850	682	1954	0.07	Yes	3.43898[a]	3.1×10^{-4}[a]
XCTD-2F	8	1850	682	1954	0.07	Yes	3.43898	3.1×10^{-4}
XCTD-3	20	1000	687	1025	0.09	No	5.07598	7.2×10^{-4}
XCTD-5	8	1850	773	1915	0.09	No	N/A	N/A

Speed allowance, profiling range, initial probe weight in fresh water, the length and diameter of probe wire, and the coefficients of the manufacturer's fall-rate equations installed in the TS-MK-130 XCTD system. The XCTD-2F is for Japan Coast Guard only.

[a]For probes with serial numbers smaller than 05011071 and not 04120989 nor 04120990, the coefficients are $a = 3.3997$ and $b = 3.0 \times 10^{-4}$.