A technology to measure deep turbulence mixing by an expendable microstructure profiler

Hua Li
Oceanographic Research Lab
JFE Advantech Co., Ltd
Nishinomiya, Japan
lihua@jfe-advantech.co.jp

Brett prairie
Mechanical Engineering Dept.
Rockland Scientific International
Victoria, BC, Canada
brett@rocklandscientific.com

Abstract— The measurements of turbulence in the deep ocean, especially close to bottom, are extremely sparse due to the difficulties of obtaining measurements at these depths. Recently, we have developed a new technology, using an expendable instrument (VMP-X, Vertical Microstructure Profiler - eXpendable), that is depth rated for 6000 m, and thus is able to reach the sea bottom and capable of measuring boundary mixing.

Keywords—Turbulence, kinetic energy dissipation rate, Shear probe.

1. INTRODUCTION

The study on turbulence mixing in the ocean is very important for understanding global ocean overturning circulations, which have strong influence in the global climate change. Most of the turbulence measurements in the ocean suggest a vertical eddy diffusivity of about 10^{-5} W/kg (Gregg, 1989), one order less than the canonical mean vertical eddy diffusivity inferred by Munk in 1966. These measurements are, however, rare and most were taken from within 1000 meters from the surface layer.

One possible reason that may contribute to this discrepancy is due to the lack of measurements on intensive mixing events in the deep ocean. Some scientists (Toole et al 1994) found evidence of enhanced turbulent mixing in the deep ocean near the bottom, particularly in regions where the bottom is rough.

We have been developing a new technology to measure deep ocean turbulence by designing an expendable vertical profiler, which may go the deep ocean up to 6000 meter, or reach the bottom instead. It may contribute to deep bottom boundary mixing research.

2. INSTRUMENTATION

The profiler is a free-fall profiler with falling speed of about 0.6-0.7 m/s. It consists of a data logger control unit, VMP-X and a non-recoverable sensor head, MicroXM. The Micro-XM communicates with the VMP-X through a fiber-optic cable. The Micro-XM is physically retained to the VMP-X through the release system, thus it may be separated from the VMP-X when instrument reaches either a target depth or the sea floor. After release, the VMP-X will float to the surface at a speed of 1.0-1.2 m/s. The Micro-XM is equipped with two shear probes (Osborn 1980) to measure turbulence velocity, and one thermistor that is used to measure temperature distribution

A. *VMP-X*

The VMP-X system (Figure1) consist of a data logger, rubber coupling, flotation, beacons and release system.

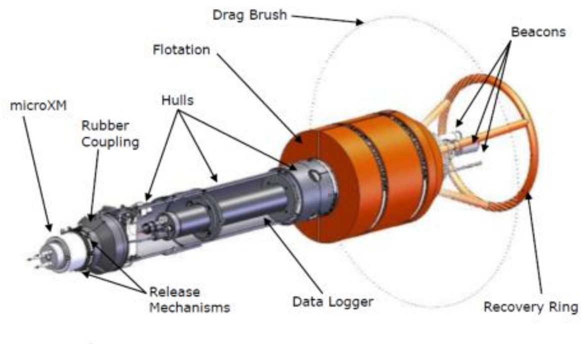

Figure 1, Partial section of the VMP-X with an Micro-XM installed

The data logger is placed inside the middle hull of the VMP-X. It is contained in a 6000m rated pressure case. The data logger communicates with MicroXM (see section C), recording data, and releasing MicroXM when it reach the target depth. The data logger has three external connectors. One is underwater optical feedthrough for connecting with the MicroXM . A two-pin underwater connector is for attaching to the burn wire release cable(See section B). The 10-pin underwater MCBH connector is used for communicating with, powering on and recharging the data logger

The front end of the VMP-X contains a rubber coupling which serves as a mounting collar for the MicroXM to be mounted physically into the profiler. The rubber material isolates mechanical vibrations from the profiler being transmitted to the MicroXM , which is main source affecting shear data.

The rear section of the VMP-X contains three pieces of flotation - two flotation collars and one core - made from syntactic foam. After an MicroXM is released upon completion of a profile, the flotation enables the VMP-X to rise back to the surface of the ocean. The syntactic foam has a maximum operational depth rating of 6000 m.

The rear end of the VMP-X is equipped with three beacons, which assist in locating the instrument after it has returned to

978-0-933957-43-5

the surface. The Iridium beacon sends accurate GPS location message every 10 minute to the Shout on the ship, allow ship staff to find the VMP-X easily when it return to surface. The VHF beacon will assist people to get the correct direction to approach the VMP-X when ship is close to the instrument. The LED Flasher will be helpful finding VMP-X during night deployment. All three beacons are operated independently in order to backup each other.

B. Release System

Physically there are there release mechanisms. The primary mechanism is the "Burn Wire" release. Should the burn wire release fail to release the MicroXM in the time intended, there are two secondary release mechanisms. If deployment is in a water no deeper than 6000m, the secondary release is the "Galvanic Link" release. For deployments in water deeper than 6000m, the secondary release mechanism is the "Rupture Disk" release.

The burn wire is a simple and effective sacrificial anode which, upon corrosion, releases the tension in the retaining hose clamp and allows the MicroXM to fall free. The burn wire assembly is connected to the output of the release board within the data logger (positive polarity); with a return path to ground - via seawater - to the cathode pin on the burn wire cable. Upon triggering a release signal, an electric potential is applied to the burn wire causing the wire to corrode and break. The entire assembly is insulated from seawater except for a small length of the loop. It is this short exposed length which concentrates the reaction at one point and allows the wire to burn quickly. The release signal will be triggered from VMP-X to 'Burn Wire' release once upon 1) the profiler stops falling, like hitting bottom; 2) loss of communication with the MicroXM; 3) the depth is deeper than preset limit; 4)the deployment time is longer than preset duration.

The galvanic link release is a passive release mechanism and involves the rapid corrosion of a linkage when in contact with seawater. The galvanic release is a secondary release mechanism for vertical deployments in water with a depth of 6000m or less. The galvanic link release is also attached to the release clamp assembly located on the front of the rubber coupling

The Rupture Disk (RD) release mechanism is a passive release mechanism and is triggered by the rupture of a thin, stainless steel (AISI 316) diaphragm when the external pressure surrounding the VMP-X exceeds 6000 decibars (8700 psi). The RD release is a secondary release mechanism for vertical deployments in water deeper than 6000 decibars to prevent flotation from being damaged. The RD has a nominal burst pressure of 5998 decibars (8700 psi) with a tolerance of +1.5% / -0.75% of the nominal burst pressure at 2°C. Therefore, the burst pressure range of the RD is 5953 decibars (8634 psi) to 6089 decibars (8831 psi) at 2°C.

After a profile has been completed and releasing finished, the VMP-X jettisons the MicroXM and the optical fiber link connecting the MicroXM to the VMP-X is severed. Although the fiber is fairly strong under tension; its strength is greatly reduced under bending. For this reason, an overhand knot must be tied in the fiber cable (Figure 2) so that when the MicroXM is released from the VMP-X, either the weight of the MicroXM , or the buoyancy force of the VMP-X (the former case is if the MicroXM is still falling, the latter case is if the MicroXM is on the bottom of the ocean) is used to decrease the bend radius of the loop, and cause the fiber to break; thus completely separating any mechanical connection between the MicroXM from the VMP-X.

Figure 2 MicroXM and data logger

C. MicroXM

The MicroXM is a non-recoverable sensor head capable of measuring turbulent microstructure and has a maximum operational depth of 6000 meters. The MicroXM is non-configurable and can only be used for one deployment. The MicroXM comes equipped with three microstructure sensors; these sensors are located at the front of the MicroXM pressure case and include two orthogonal shear probes (x-axis and y-axis) and one temperature probe. Also, located at the front of the MicroXM pressure case is a pressure transducer. Inside the pressure case are two orthogonal piezo-ceramic accelerometers (x-axis and y-axis) and a y-axis pitch sensor.

To turn on the MicroXM , a magnet must be attached to the MicroXM pressure case to activate a Reed switch. The MicroXM is battery powered and is not user-serviceable. The battery provides 12 hours of use. In comparison, the typical time duration for a vertical profile to 6000m using an MicroXM attached to the VMP-X is 3 hours. All data acquired from the MicroXM is transmitted via a single-mode optical fiber cable located at the rear of the MicroXM pressure case.(Figure 2)

3 FIELD TEST

In September of 2014, a field test was conducted together with scientists from the Oceanology Institute of South China Sea, using research vessel ShiYan 3 at south area of Southern China Sea. Total of 4 profiles were carried out. One cast reached only the 60 m, where VMP-X released the MicroXM because of bad communication between the sensor head and data logger. The other three casts went to deeper waters over 4000 m, in which, one profile was released just 100 m above bottom, two of them hit the bottom.

The profiler falls freely in the sea water at about 0.6 m/s at surface, and dropped slowly to 0.56 m/s at 4300m, due to the increasing of water density (Figure 3). The pitch angle showed that profiler moved downward with attack angle of less than 1 degree, thus, the shear sensors may work perfectly. Spikes in Figure 3 are duo to the bad data transmission through fiber.

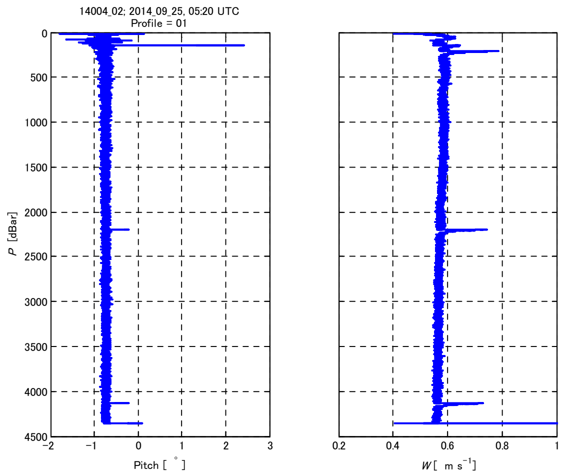

Figure 3, The pitch angle and fall rate of VMP-X

Signal insensitivities from the shear sensors are close to the noise level in the deep ocean, even the bottom layer, suggested weak mixing caused by turbulence. All three profiles showed the same scenario with low turbulence mixing in the deep ocean. (Figure 4)

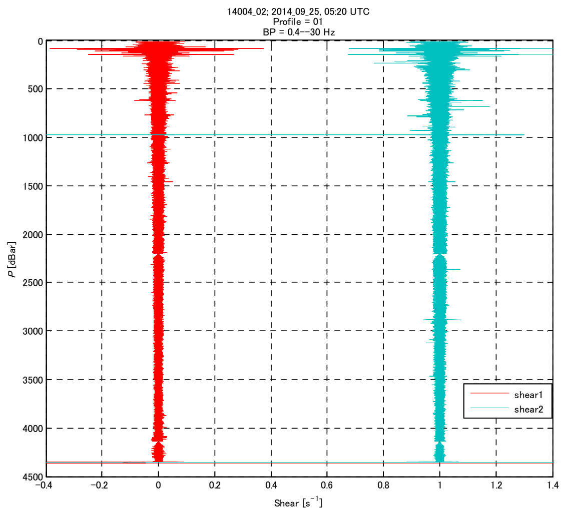

Figure 4, Shear signals from cast 4 during test experiment in South China Sea

The turbulence energy dissipation rate is estimated based on isotropic assumption (Osborn),

$$\varepsilon = 7.5\nu\overline{\left(\frac{du}{dz}\right)}^{2} \qquad (1)$$

where $\nu = 1 \cdot 10^{-6}$ m^2s^{-1} is the kinematic molecular viscosity, the over-line indicates a spatial or ensemble average, *u* is a velocity component. *z* is co-ordinate orthogonal to the velocity component,

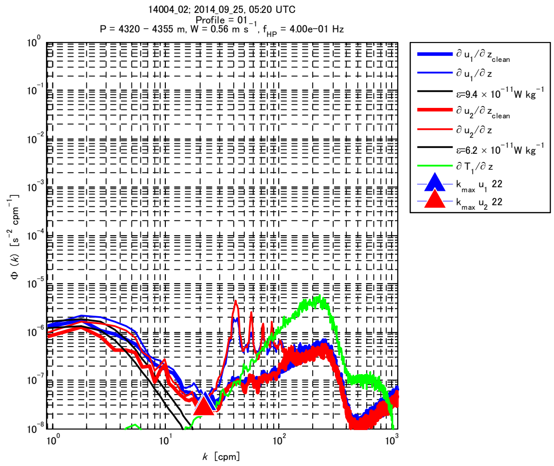

Figure 5, Shear spectra fit with Nasmyth Spectrum at layer of 4320 to 4355 meter.

In the deep ocean, even the bottom boundary layer showed weak turbulence as low as less than 10^{-10} W/kg. In another aspect, the data also proved that the VMP-X has very low noise level and is applicable to full deep ocean turbulence mixing measurement.

One of the main purposes developing the expendable VMP-X is on the consideration of high risk of damaging the profiler when scientists are desired to do research on bottom mixing. VMP-X triggers the release systems relatively easy when reaching hard rock seafloor. However, soft mud may cause the profiler to be stuck in the mud and consequently, causing the loss of the instrument.

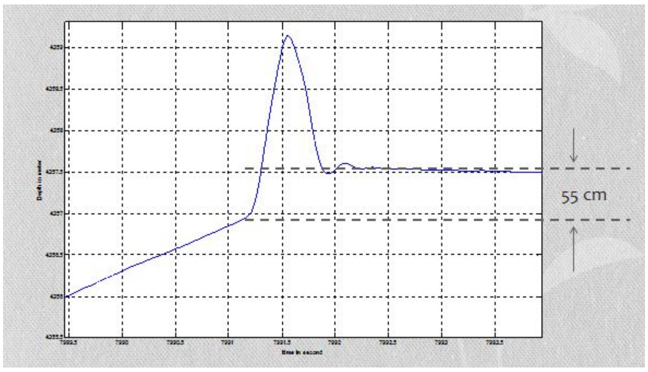

Figure 6, Pressure signal showed the depth that VMP-X being inserted into mud

The cast 4 showed (Figure 6) that the instrument hit the bottom and being inserted into soft much about half meter. It caused the VMP-X to be stuck about 2 minutes. Finally it was self-released by buoyance after MicroXM being jettisoned and safely moved back to the surface .

4 Summary

VMP-X is designed to be a low cost alternative/supplement to conventional vertical microstructure profilers (Lueck et al 2002), obtaining microstructure measurements where using a conventional profiler may not be desirable or may add unwanted risks (such as bottom boundary layer turbulence measurements). As such, the MicroXM is non-configurable and can only be used for one deployment. Such configuration will allow scientists to obtain mixing data as close as possible to the bottom, lowering the risk of damage, or even loss of the instrument.

The VMP-X has very good low electronic and mechanical noise level, thus, allows full deep ocean turbulence mixing measurement available with safety and low cost.

ACKNOWLEDGMENT

Thank you to the Captain and crew of the *R/V Shinyan 3* for their assistance with the deployment of the VMP-X Profiler. We also acknowledge the great help by scientists from Oceanology Institute of South China Sea.

REFERENCES

[1] *Gregg, M. C. (1989), Scaling turbulent dissipation in the thermocline, J. Geophys. Res., 94, 9,686–9,698.*

[2] *Lueck R, G (2002), Oceanic Velocity Microstructure Measurements in the 20th Century. Journal of Oceanography*, Vol. 58, pp. 153 to 174, 2002

[3] *Munk, W (1966) Abyssal recipes. Deep-Sea Research 13, 707-730*

[4] *Osborn, T. R. (1980): Estimates of the local rate of vertica diffusion from dissipation measurements. J. Phys. Oceanogr., **10**, 83–89*

[5] *Toole, J. M., K. L. Polzin, and R. W. Schmitt (1994), Estimates of diapycnal* mixing in the abyssal ocean, Science, 264, 1120– 1123..