HIDEX Generation II: A New and Improved Instrument for Measuring Marine Bioluminescence

Edith A. Widder, Charles L. Frey, Lawrence J. Borne

widder@hboi.edu lfrey@hboi.edu borne@hboi.edu

Harbor Branch Oceanographic Institution
5600 US 1 North
Ft. Pierce, FL. 34946 USA

ABSTRACT

The Engineering Division of Harbor Branch Oceanographic Institution, in a collaborative effort with the HBOI Marine Biophotonics Center and the Naval Oceanographic Office, have developed a new and improved instrument for measuring bioluminescence in the oceans.

Known as the High-Intake Defined Excitation Bathyphotometer (HIDEX-BP), this instrument was originally developed by the University of California at Santa Barbara, and has become the US Navy's standard bioluminescence measurement tool.

HIDEX Generation II is a newly re-designed, fully integrated system, featuring an improved light collection chamber, a new remote telemetry and data acquisition system, and an improved oceanographic sensor suite.

This paper discusses the design, development, and theory of operation for the HIDEX II instrument. Results of sea trials and field data collection will also be presented.

INTRODUCTION

Bioluminescent plankton occur in all the world’s oceans. In regions of very dense concentrations of these organisms, bioluminescence may be responsible for brilliant nocturnal displays, where any agitation of the water, as from a passing ship or a swimming dolphin, leaves a shimmering track. The measurement of bioluminescence therefore serves as a valuable indicator of organism distribution patterns.

Bathyphotometers, which are specifically designed to measure stimulated bioluminescence, generally consist of a light-tight chamber with a light detector that measures bioluminescence from water, containing organisms, drawn through the chamber. Early designs of such instruments employed low flow rates and short residence times, because the presumption was that dinoflagellates constituted the dominant source of hydrodynamically stimulated bioluminescence in the euphotic zone, where most such measurements were made. However, there are many luminescent zooplankton such as copepods, ostracods, euphausiids, medusae, siphonophores, ctenophores and larvaceans [2], which produce flashes that may be orders of magnitude brighter and of longer duration than dinoflagellate flashes. Additionally, because zooplankton may be able to evade capture by low flow systems, there were concerns that bathyphotometers were underestimating the contribution of zooplankton to measurements of bioluminescence potential. There were also concerns that measurements were "instrument specific" and therefore not comparable, because different flash durations and the ability of some organisms to produce multiple flashes meant that the measured photon flux depended on such factors as the detection chamber volume, the flow rate through the chamber, the method of stimulation and the amount of prestimulation which occurred due to light baffling.

The HIDEX-BP (high intake defined excitation bathyphotometer) was developed [1] with funding from the Naval Research Laboratory's Tactical Oceanographic Warfare Support office in response to a requirement formulated within the U.S. Navy oceanographic community for a standardized bathyphotometer design. This bathyphotometer had a variable speed pump that permitted pumping rates up to 44 $l\ s^{-1}$, which insured minimal zooplankton avoidance and excellent sampling statistics as compared to previous bathyphotometers, which generally pumped at 1 $l\ s^{-1}$ or less. In order to measure the total photon flux of even long duration flashes at high pumping rates a very long detection chamber (130 cm long) was designed with an array of optical fibers embedded in the walls to collect light and direct it to a photomultiplier tube. Bioluminescence was stimulated by hydrodynamically calibrated flow through a turbulence generating grid at the entrance to the detection chamber. In order to characterize the luminescence, an event counter and zone array were subsequently incorporated into the design [3]. The event counter consisted of a ring of fiber optics coupled to a second photomultiplier tube and optically designed to sample a narrow cross section of the chamber, a short distance downstream from the excitation grid. The zone array consisted of eight equally spaced PMTs viewing narrow cross-sections along the length of the detection chamber in order to measure the kinetics of the population flash and ensure that flow rates were optimized to measure the total photon flux of the population flash.

The HIDEX-BP was delivered to The U.S. Navy (Naval Oceanographic Office) in 1990 and has been in continual use ever since, monitoring bioluminescence in the world oceans and adding to the Navy's environmental data base. As it was recently determined that this first generation HIDEX-BP was reaching the end of its useful life span, we were tasked by NAVOCEANO with developing the next generation HIDEX-BP. Requirements for the GEN 2 system included:

1. A modular design incorporating commercial off-the-shelf components to facilitate long-term maintenance.
2. A new software data acquisition package using a standard Windows® interface in order to eliminate the need for custom post-processing software.
3. Addition of new sensors to meet expanded measurement requirements.

HIDEX II COMPONENTS

The HIDEX Gen-II System consists of 3 major components:

1. The HIDEX subsea profiling package, or “skid”.
2. A deck winch and lightweight sheave.
3. The topside computer and HIDEX power supply consoles.

Fig. 1: HIDEX II Profiling Package (skid)

DETECTION CHAMBER ASSEMBLY

The detection chamber assembly is the heart of the HIDEX-BP system. It consists of four major parts: a rotating light baffle at its entry, followed by an excitation grid, the detection chamber itself, and an aft flowmeter & pump assembly. The original “event counter” ring was eliminated from the new HIDEX II detection chamber assembly, as it was felt that it was unable to distinguish individual bioluminescent events in the “glowing soup” of the open ocean.

Rotating Helical Light Baffle

The rotating light baffle (Fig. 2) is located near the entrance of the tube and is the first thing encountered by organisms as they enter. Its purpose is to block any external light from entering the detection chamber. Its helical shape and free rotation is designed to minimize any significant stress to the organisms, thus reducing pre-stimulation of the organisms before they reach the excitation grid.

Fig. 2: Helical light baffle with excitation grid

Excitation Grid

The excitation grid is located just behind the light baffle. It is a stainless steel plate, with approximately 35% obscured area, that mounts inside the flow tube. Its purpose is to disrupt the flow causing uniform fields of turbulence and high shear stress in the water. This grid is the principle source of stimulation for the organisms as they enter the detection chamber.

Detection Chamber

The detection chamber consists of a 1.3m PVC pipe through which seawater and its entrained organisms continually flow. Bioluminescent organisms entering the tube are stimulated as they pass through the detection grid. The flash events are then captured in the chamber in the form of a standing light wave of varying intensity. This light is collected by a series of fiber optics and routed to Photo-Multiplier Tubes (PMTs). To accomplish this, two distinct array of fiber optics line the chamber (Fig. 3).

Fig. 3: Detection chamber with fiber-optic penetrators

Zone Array

The first, is a series of 8 pairs of wedge-shaped optical lenses, known as the Zone Array. Each pair of lenses forms a top-bottom optical "slice", collecting light in a small isolated cross-section of the chamber. These lenses each contain 4 optical fibers, offering HIDEX II a distinct advantage in sensitivity over HIDEX I, which used only 2 fibers per window. Each bundle of 8 fibers is then routed to a dedicated PMT. Thus, the Zone Array in total is comprised of 8 slices with 8 fibers each and 8 individual PMTs. This allows comparative light measurements to be made between different regions of the detection chamber, such that flash dynamics can be captured as the organisms are stimulated and subsequently decay as they travel through the chamber. The data from the Zone Array is also used to create a metric for a bioluminescent event, known as the E-Fold factor, which is defined as "*the amount of time it takes a bioluminescent event to decay from its peak by one natural log unit.*" This E-Fold factor is essential in classifying the species present in a given sample volume.

Total Light Array

The second network of fibers is located throughout the length of the detection chamber, and is known as the Total Light Array. The TL Array consists of 72 single fiber optic strands looking into the detection chamber at evenly spaced intervals. These strands are all routed to a single large-aperture PMT. This offers measurement of the Total Light generated by all organisms within the detection chamber in photons/l/s. This offers a measurement of the total bioluminescent potential in that same sample volume.

Flowmeter & Pump Assembly

At the end of the flow tube is a simple turbine-driven flow-meter used to determine volumetric flow rate (typically 18 l/s). Aft of the flowmeter is a magnetically-coupled brushless motor-driven pump. The pump draws water through the tube and expels it past a conical diverter plate, radially outward at the aft end. This avoids sending the HIDEX sailing forward like a torpedo at such high flowrates. The impeller on the pump also acts as a light baffle, keeping any outside light from entering at the aft end of the tube.

Fig. 4: Main pump & flowmeter assembly

ANCILLARY INSTRUMENTS

One major improvement made to the HIDEX Gen-II system was an enhanced ancillary sensor suite, and the addition of spare input channels (RS-232 & Analog) for future add-ons. This sensor package is used to augment bioluminescent measurements with simultaneous environmental data that gives clues about optimal conditions for bioluminescent activity. The sensor suite includes the following instruments:

1. SeaBird SBE-37SI CTD
2. WetLabs AC-9 Multi-spectral Transmissometer
3. WetLabs LSS Turbidity Sensor
4. C-Star Blue Transmissometer
5. Chelsea Instruments MiniTracka-II Fluorimeter
6. Tritech 100m Altimeter (for avoiding bottom collision during profiling)

PMT HOUSING

The PMT housing (Fig. 5) contains 8 Zone Array PMTs, one Total Light PMT, and their accompanying amplifier cards. There is also a gain controller card which contains a microcontroller for performing auto-gain and high-voltage switching functions. These cards, designed by HBOI, offer the HIDEX II system a wide dynamic range, from about 10^{9} ph/s to 10^{14} ph/s (Total Light).

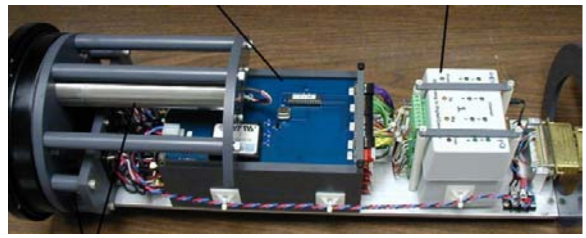

Fig. 5: PMT Housing Internals

TELEMETRY & CONTROL HOUSING

Communication with the topside computer, data acquisition, and instrument control is contained in the main telemetry housing (Fig. 6). Data acquisition is accomplished by three 8-channel stand-alone programmable A/D converters (CyberSense CYQ-508), two of which are located in the PMT housing. These ADCs communicate, along with the CTD and AC-9 over RS-232 serial channels to a pair of data multiplexers (OceanTools OceanMUX). Additionally, an RS-232 controlled relay card (NCD R-165) is used to switch power to the main pump, PMTs, and ancillary instruments.

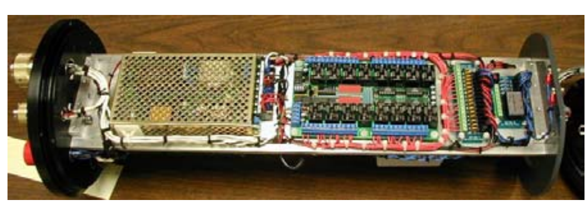

Fig. 6: Telemetry Housing Internals

TOPSIDE COMPONENTS

Deck Winch

The HIDEX II system is designed to be loaded on to ships of opportunity within the Naval Oceanographic Office (NAVO) fleet. Thus, a dedicated deck winch and sheave were provided. The winch is a 20HP, 1K model, built by HBOI's Engineering subsidiary, Ocean Engineering & Production, Inc. (OE&P). This electric-hydraulic winch has a 5000lb. bare-drum line pull capacity and 75 ft/min line speed. For this application, it was spooled with 500m of custom oceanographic cable dedicated to the HIDEX II system. Additionally, it provides a digital readout of the skid's altitude above the bottom for operator feedback during deployment.

Fig. 7: OE&P 1K Deck Winch

Computer & Power Supply

For HIDEX II, the topside power supply and computer consoles have been consolidated into two standard 19" mini-racks, each in their own shock-resistant shipping containers.

The power console (Fig. 8), provides power to the subsea instrument package, main pump, and provides ground-fault interruption protection.

The computer console (Fig. 9) consists of a 900MHz Pentium-III based rack-mount PC running Microsoft Windows 2000, a slide-out keyboard, LCD monitor and touchpad, and the topside portion of the serial data multiplexers & telemetry system. It also provides one dedicated video channel to the HIDEX which is currently unused.

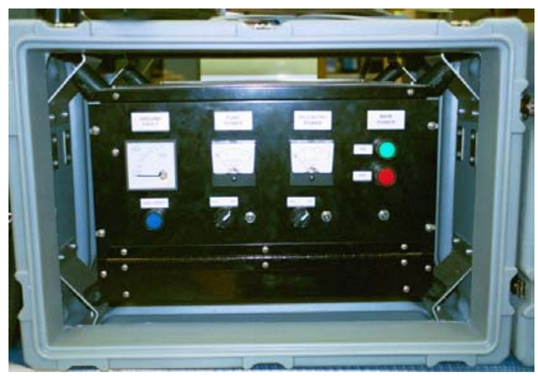

Fig. 8: Topside Power & GFI Console

Fig. 9: Topside Computer & Telemetry Console

SOFTWARE

Another major enhancement made to the HIDEX II system is a completely re-designed custom software package. This software offers a new, easy to use, Windows Graphical User Interface (Fig. 10), including all control, configuration, data display, and logging features, in one application. All PMTs and ancillary instruments (with the exception of the AC-9) are acquired and displayed in the HIDEX II package. From here, the user can configure communications settings, set calibration scales & offsets, and control subsea instruments.

The datalogging functions store both raw and processed data in a simple tab-delimited Microsoft Excel spreadsheet format, for easy viewing and post-processing.

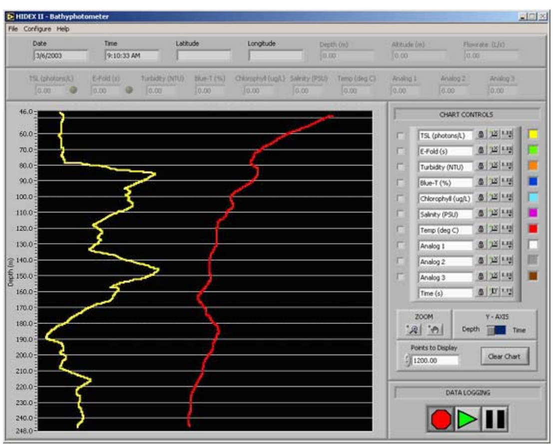

Fig. 10: HIDEX II Main GUI

SEA-TRIALS

Following laboratory calibration at HBOI's Marine Biophotonics Center, the HIDEX II system was tested alongside its predecessor at sea for the first time in February of 2003. Testing proceeded smoothly with excellent results and near-perfect correlation between the instruments. The system is expected to go into full-time worldwide service in August.

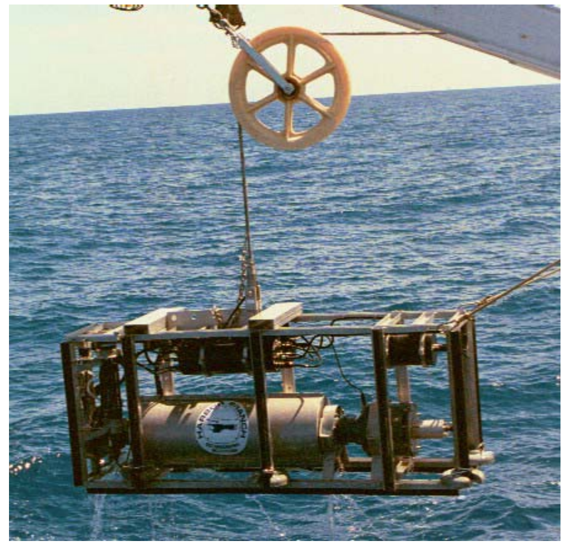

Fig. 11: HIDEX II Field Deployment

CONCLUSION

In this paper, an overview of the new HIDEX Generation-II Bathyphotometer has been presented. Included were discussions about its use, history, system architecture, and design enhancements over previous versions. After successful sea-trials, the HIDEX II package is now ready for use by the Naval Oceanographic Office.

While the Gen-II represents a newly re-designed upgrade of the field proven HIDEX Gen-I BP, it should also be noted that work is underway at Harbor Branch for the design of a radically enhanced Bathyphotometer system, the HIDEX Gen eration-III. This instrument will feature significant improvements in light collection optics, sensitivity, data rate, and post-processing capabilities. Furthermore, it will offer in-situ biological sampling and intensified video images, thereby allowing biological "ground truthing" of the instrument, as well as interface to other BPs for comparison and calibration.

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