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Calibration of the CUMA Diagnostic Unit

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Calibration of the CUMA Diagnostic Unit

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DEFENCE AND CIVIL
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CALIBRATION OF THE CUMA DIAGNOSTIC UNIT

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Executive Summary

Dynamic mixing of breathing gases in a diving set requires constant monitoring of the oxygen partial pressure to alert the diver of failures. The CUMA (Canadian Underwater Mine-countermeasures Apparatus) is a self-contained, underwater breathing apparatus that mixes oxygen and a diluent gas (in CUMA helium is used) to provide the diver with a breathable mixture. The mass flow of oxygen remains constant throughout the dive while the helium flow increases linearly with depth; thereby, holding the oxygen partial pressure of the gas mixture constant. A secondary gas supply circuit known as the bypass circuit provides breathable gas but the oxygen partial pressure is not held as steady. A method is required to accurately monitor the oxygen content of these gas mixtures.

In the CUMA a galvanic oxygen fuel cell is used to measure the oxygen partial pressure of the mixtures during the dive as well as during the pre-dive calibration of the gas mixing circuits. It is important that the oxygen analyser itself be calibrated to ensure the best calibration of the apparatus and the safe performance during a dive.

The current procedure calibrates the CUMA oxygen analyser to 1.0 atmospheres, absolute (ATA). This distributes the analyser error across the full operational range of the CUMA, i.e., 0.18 ATA to 1.8 ATA. Unfortunately, this moves the largest error to the particular ranges of interest—near 0.18 ATA, where the bypass is calibrated, and near 1.8 ATA, the upper range of the main gas mixing circuit during a dive.

To improve the accuracy of oxygen measurement for calibration of the main gas mixing circuit, a proposal is made to shift the calibration point for the analyser to 1.5 ATA. This is the mid-point of the operating range of the CUMA main gas mixing circuit (1.2 ATA to 1.8 ATA). The result is to split the error across the gas mixing circuit operating range.

Unfortunately, the move to 1.5 ATA increases the error in the range where the bypass gas is calibrated. The problem can be solved by a new method for calibrating the bypass gas mixture developed by the CUMA manufacturer. The method uses a hand-held flowmeter to verify the oxygen and total mixtures are within allowable ranges. Using the flowmeter method eliminates the need for accuracy of the oxygen analyser in the 0.18 ATA range.

In conclusion, by using a flowmeter rather than the CUMA oxygen analyser to calibrate the bypass gas mixture, the oxygen analyser's maximum accuracy can be used for the operational range of the main gas mixing circuit.

Table of Contents

List of Figures

January 4, 2000

Calibration of the CUMA Diagnostics Unit

David Eaton, M.Sc., P.Eng.

An explanation on the selection of the CUMA Diagnostic Unit calibration point using error minimization as a criteria.

INTRODUCTION

The Canadian Underwater Mine-countermeasures apparatus dynamically mixes oxygen and helium relative to the depth of the diver [1,2]. The deeper the diver goes the more helium added to dilute the oxygen. A diagnostic unit measures the oxygen concentration of the mixed gas and informs the diver whether it is safe to breathe or not. The oxygen analyzer in the diagnostic unit uses a galvanic cell (called an O_2 fuel cell) that produces an electrical output proportional to the oxygen partial pressure (PO_2) of the mixture. The electrical output is amplified to produce a voltage readable as oxygen partial pressure in atmospheres, absolute (ATA). The partial pressure is compared with the pre-set high and low limits. When the PO_2 is within the high and low limits a green light is activated in the diver's mask. If the PO_2 goes beyond the high or low limit the light changes from green to red. If the red light persists the diver aborts the dive.

The diagnostic unit is also used to calibrate the gas mixing circuit and the bypass circuit during the pre-dive setup. The gas mixing circuit is pressurized to 9 ATA and the helium flow is adjusted to obtain the correct PO_2. The diagnostic unit measures and displays the PO_2 of the gas mixture. Bypass gas is passed through the diagnostic unit at ambient pressure to establish its oxygen concentration. Therefore, for both pre-dive calibration and during the dive, it is important that the oxygen analyser be calibrated to give the best possible measurement for the PO_2 range used in CUMA.

CURRENT CALIBRATION METHOD

The goal of the calibration is to have a measured PO_2 as close to the actual PO_2 as possible. Ideally, the relationship between the measured and actual values would be a one-to-one relationship like the solid line in Figure 1. Unfortunately, the galvanic cell, like most real-world devices, does not follow this perfect relationship. The output of the analyzer, dashed line in Figure 1, tends to drop off as the PO_2 gets higher. The amount of droop tends to increase the longer the cell is used.

The calibration of the oxygen analyser is accomplished at a single PO2 level using a simple gain circuit. This does nothing more than shift the analyser output curve up or down. The CUMA was originally calibrated to measure 1 ATA with pure oxygen flowing through the analyzer at atmospheric barometric pressure (assumed to be 1 ATA). This shifted the curve as shown in Figure 2.

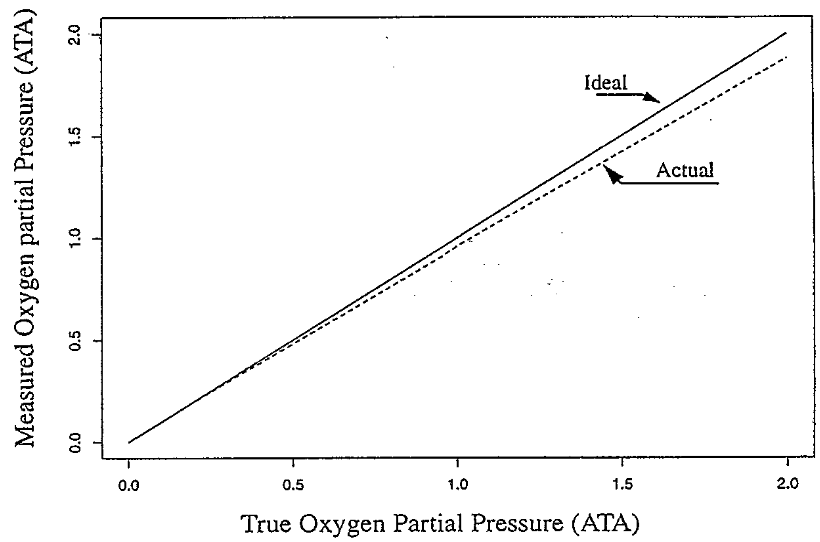

Figure 1. Ideal calibration versus actual diagnostic output curve.

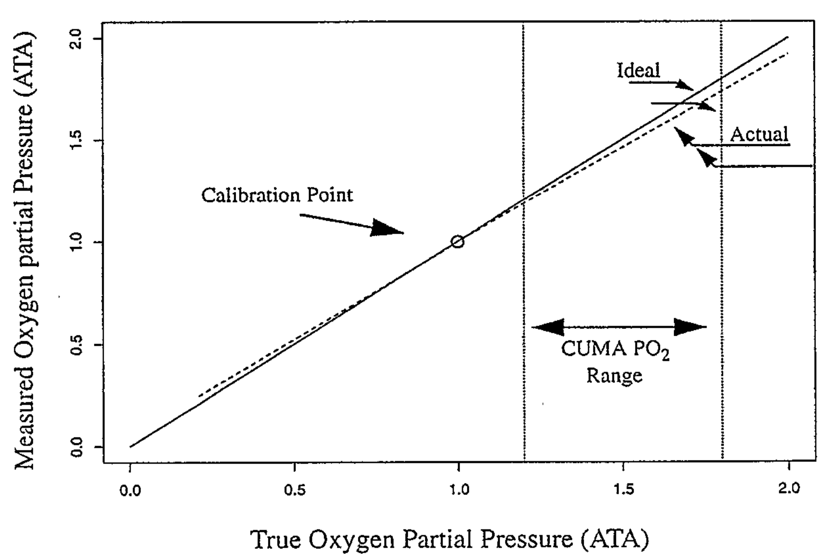

Figure 2. Calibrating the diagnostics unit at 1.0 ATA shifts the actual output curve up to minimize the error in the area of 1.0 ATA but not in the CUMA PO2 range.

There were two problems with this method. The first was the assumption that the barometric pressure in the calibration location was 1 ATA. At DCIEM the barometric pressure is rarely 1 ATA and more often is lower by 0.03 ATA. A similar range around 1 ATA will be found at sea level diving units. The second problem was that the main gas mixing circuit of the CUMA is designed to supply gas near 1.6 ATA and not outside of the range between 1.2 ATA and 1.8 ATA. As can be seen from Figure 2, calibrating at 1 ATA brought the lower portion of the curve (0 to 1 ATA) fairly close to the ideal line. However, the main gas mixing circuit operating range (between the two vertical lines) is still below the ideal curve.

PROPOSED CALIBRATION METHOD

One solution is to calibrate at either 1.2 or 1.8 ATA, but the problem is similar to the 1.0 ATA calibration point, i.e., the error between the measured and ideal gets greater as the PO_2 moves away from the calibration point. This concentrates the error at one end of the operating range.

A better solution is to calibrate at the mid-point of the range, i.e., 1.5 ATA, as in Figure 3. Here the error is split between both ends of the range and the greatest accuracy is found at 1.5 ATA. It is clear that rather than all of the error being concentrated at one end of the range it is split on either side of the calibration point. The maximum error is now reduced to about one half of what it would be if either the high or low limit were used and even less than one half the error associated with calibrating at 1.0 ATA.

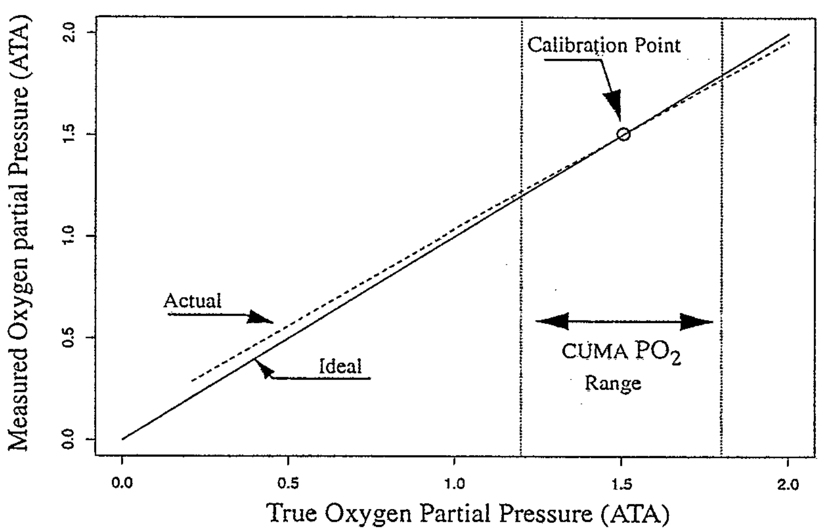

Figure 3. Calibrating inside the CUMA PO2 range distributes the error.

The problem is complicated, however, by the calibration of the bypass. The bypass gas mixture oxygen concentration is calibrated at or near 1 ATA ambient pressure. The allowable PO_2 range of the bypass gas at this pressure is from 0.18 ATA to 0.22 ATA. In Figure 3, it is clear that calibrating the diagnostic oxygen analyser at 1.5 ATA shifts the error from the operating range of the gas mixing circuit to the lower end of the PO2 range. This is exactly the calibration range of the bypass gas mixing circuit.

The solution comes from a simplified method of calibrating the bypass gas mixture developed by Carleton Life Support Technologies's Fullerton Sherwood Division, the manufacturer of the CUMA. A flowmeter is used rather than use the diagnostic unit to calibrate the bypass gas mixture. First the oxygen flow is checked against the flowmeter. Then the total flow is checked against the flowmeter. The scale of the flowmeter is calibrated to show the allowable range of both flows. If both the oxygen flow and total mixed gas flow are within the allowable ranges then the bypass is calibrated. If not, the appropriate adjustments are made to the driving pressure. Consequently, the diagnostic oxygen analyser calibration range does not need to extend below 1.2 ATA

CONCLUSION & RECOMMENDATIONS

The proposed method for calibrating the CUMA Diagnostic Unit oxygen analyser combined with the flowmeter method of calibrating the bypass gas mixture will provide the best possible measurement for the PO_2 range used in CUMA. These procedures should be incorporated in the CUMA calibration and the CUMA manuals should be amended to reflect this procedure. If the operating range of the CUMA changes, then the calibration procedure should be reviewed to ensure that the calibration point is in the centre of the range.

REFERENCES

1. Eaton D (1988) Canadian Underwater Mine Apparatus: Manned evaluation of the first prototype. DCIEM No. 88-TR-31, June 1988.
2. Chapple JCB and Eaton DJ (1992) Development of the Canadian Underwater Mine Apparatus and the CUMA mine countermeasures dive system. DCIEM No. 92-06, Feb 1992.

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Dynamic mixing of breathing gases in a diving set requires constant monitoring of the oxygen partial pressure to alert the diver of failures. The CUMA (Canadian Underwater Mine-countermeasures Apparatus) is a self-contained, underwater breathing apparatus that mixes oxygen and a diluent gas (in CUMA helium is used) to provide the diver with a breathable mixture. The mass flow of oxygen remains constant throughout the dive while the helium flow increases linearly with depth; thereby, holding the oxygen partial pressure of the gas mixture constant. A secondary gas supply circuit known as the bypass circuit provides breathable gas but the oxygen partial pressure is not held as steady. A method is required to accurately monitor the oxygen content of these gas mixtures.

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Canadian Underwater Mine-countermeasures Apparatus

Rebreather

UBA

Closed-Circuit

Semiclosed-Circuit

Oxygen fuel cell

Oxygen analyser

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