COMPONENT SAFETY ASSESSMENT: MECHANICAL ROBUSTNESS OF TELEDYNE R22 OXYGEN SENSORS

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ORIGINATOR:	**Dr. Alex Deas, Dr. Bob Davidov, Viktor Sudakov, Mihail Solovyev**
DEPARTMENT:	**Engineering**
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Revision History

Revision	Date	Description
A	4rd Apr 2007	Originated, with mechanical tests of B7 batch
A1	10th Sept 2007	Updated with test results of F7 batch
A3	21th Sept 2007	Updated with 3m drop test results of B7 batch with fresh sensor
A4	19th Oct 2007	Completed proof reading and review. Approved for issue

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1. PURPOSE AND SCOPE

This document describes the results of mechanical robustness tests of the Teledyne R-22D oxygen sensor for suitability for use in a rebreather. The sensors tested were two samples from a B7 batch, manufactured in February 2007, and three samples from a custom F7 batch, manufactured in June 2007.

The tests performed correspond to Test 6 in the Test Schedule described in the Deep Life document entitled "Oxygen Cells for Dive Applications: Sourcing, Performance, Safety and Reliability: Results of a 6 Year Study"[1] and will be updated to the internal version of that document – data on the Teledyne sensors had been withheld from the public document due to performance issues.

2. MEASUREMENT EQUIPMENT

2.1. Portable multimeter.

Type: Mastech M890G

- Samples per second 2-3
- DC voltage range 0,1mV-1000V (0÷200mV; 0÷2V; 0÷20V; 0÷200V;0÷1000V)
- AC (40-400Hz) voltage range 0,1mV-700V (0÷2V; 0÷20V; 0÷200V;0÷700V)
- DC current range 1uA-10A (0÷2mA; 0÷20mA; 0÷200mA;0÷10A)
- AC (40-400Hz) current range 10uA-10A (0÷20mA; 0÷200mA;0÷10A)
- Resolution ±0.1% of range
- Frequency range 1Hz-20kHz
- Resistance range 0,1Ohm-200MOhm
- Capacity range 1pF ÷20uF
- Input impedance 10MOhm

Calibrated August 2007.

3. TEST RESULTS FOR SENSORS FROM BATCH B7

A Teledyne type R-22D OXYGEN SENSOR with Serial_number: 855166 was used for this test: the date code was B7, meaning it was manufactured in February 2007.

3.1. Hard Drop tests from 1.5m and 3m with a sensor from batch B7

Table 1: 1.5m drop test with B7 sensor onto a wooden block

Drop №	before the tests	1	2	3	4	5	6	7	8	9	10	mV drop	% drop
Sensor SN:855166 output	12.2	11.5	7.7	7.6	7.9	7.3	6.8	8.5	8.1	15.5	53.3	41.1	337

[1] Report available online at http://www.deeplife.co.uk/or_files/DV_O2_cell_study_070329.pdf

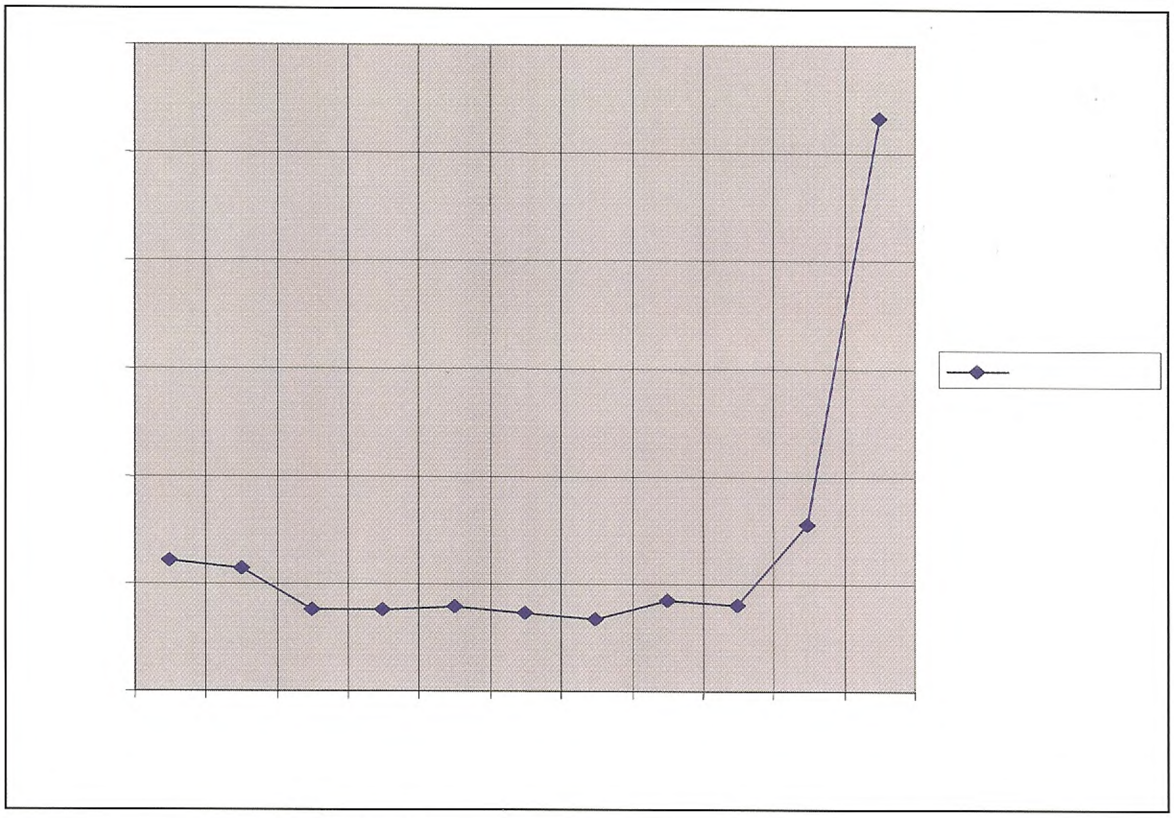


Fig 3-1: B7 sensor output during 1.5m drop tests.

During the 1.5m drops, an initial decrease in the output signal was registered. After the 7th drop the signal began to increase. After the 10th drop the output signal was the same as for situations when there was a 100% O2 flow on the sensor or when the sensor electrolyte was leaking. During the pause between the 1.5m and 3m tests, the signal decreased slowly and dropped to 41.1mV before the 3m drop test began.

It is concluded that the sensor failed on the tenth of the eleven 1.5m drops, and deteriorated immediately with the 3m drops.

Table 2: 3m drop test with B7 sensor

Drop №	before the test	1	2	3	4	5	6	7	8	9	10	mV drop	% drop
Sensor SN:855166 output	41.1	8.0	8.2	7.7	6.9	6.6	10.5	5.0	4.1	6.8	6.4	34.7	84

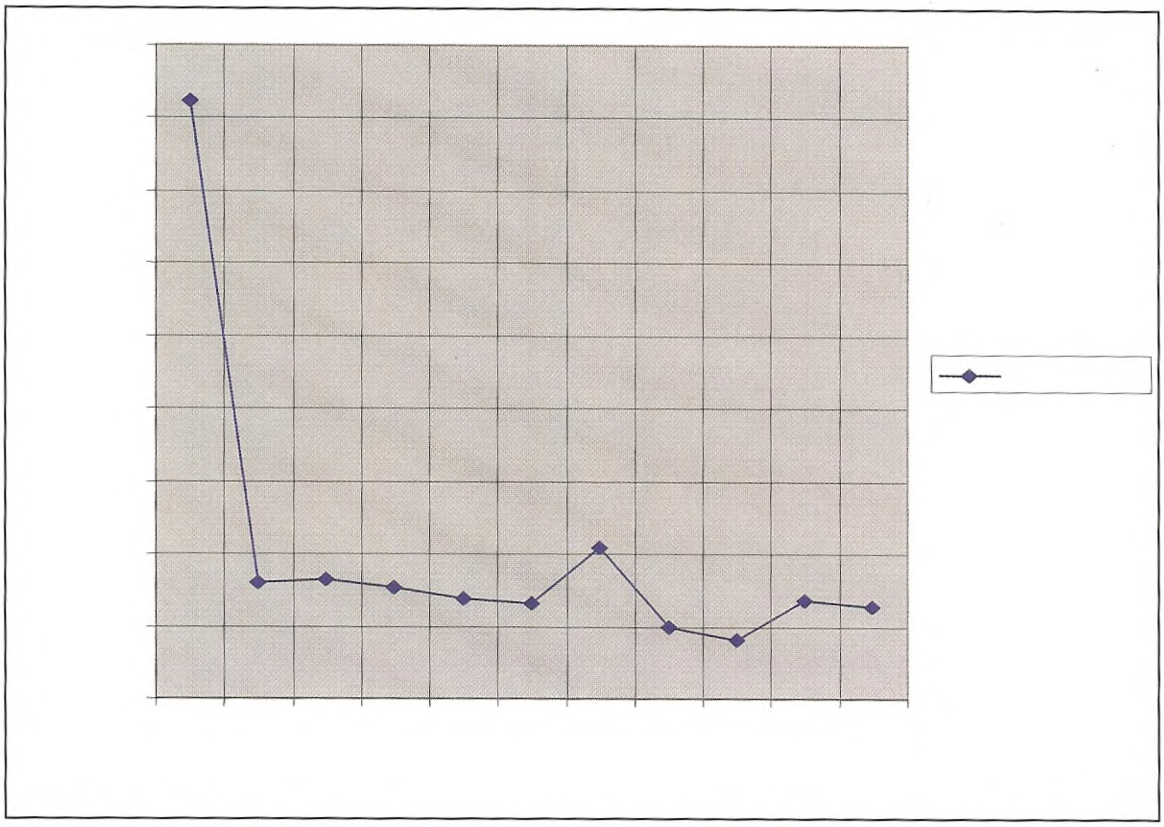


Fig 3-2: B7 sensor output during 3m drop tests.

After the third 3m drop, a knocking noise was noticed when the sensor was shaken. After the sixth 3m drop, small drops of electrolyte were noticed on the sensor's membrane (Fig 3-3). After the eighth 3m drop, a small dent was noticed near the sensor connector (Fig 3-4).

Fig 3-3: Electrolyte drops on the sensor membrane

Fig 3-4: There is a small dent near the connector hole of the sensor

3.2. Retest for 3m drops using a fresh sensor from the same batch

Sensor Serial number 855165, with date code B7, was tested without having suffered any previous 1.5m drops.

Table 3: 3m drop test with replacement B7 sensor

Drop №	before the test	1	2	3	4	5	6	7	8	9	10	mV drop	% drop
Sensor SN:855165 output	10.2	9.5	8.9	7.5	7.6	8.6	7.6	7.2	7.8	7.2	7.1	3.1	31%

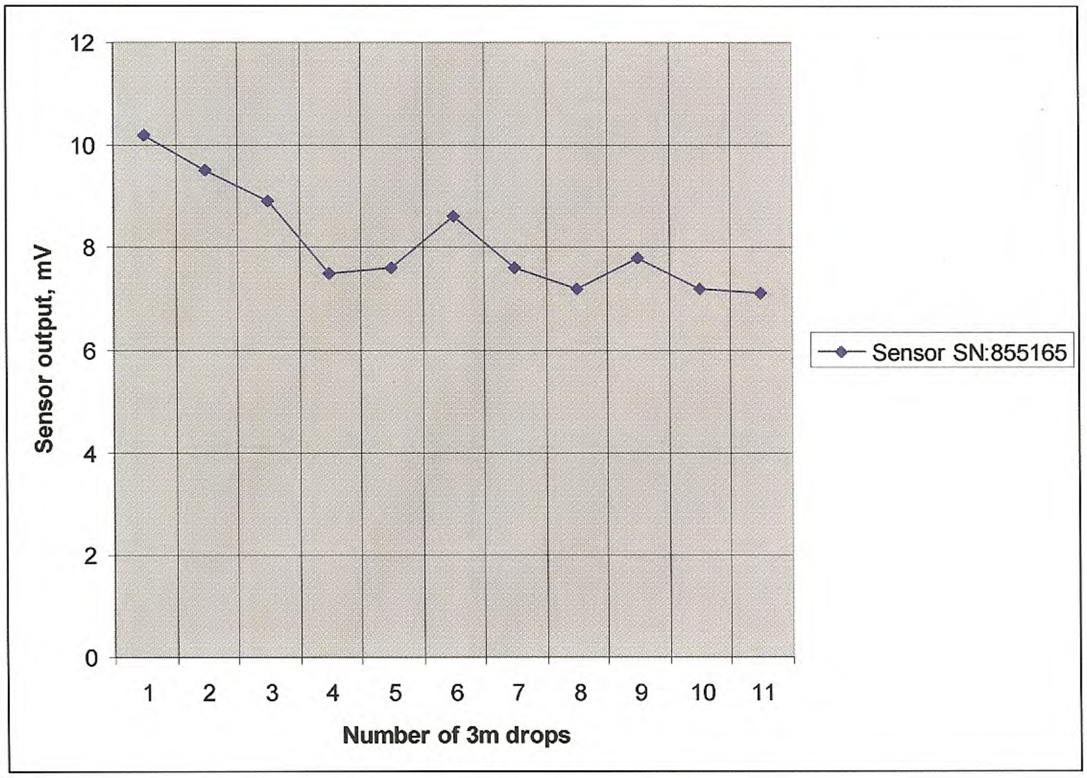
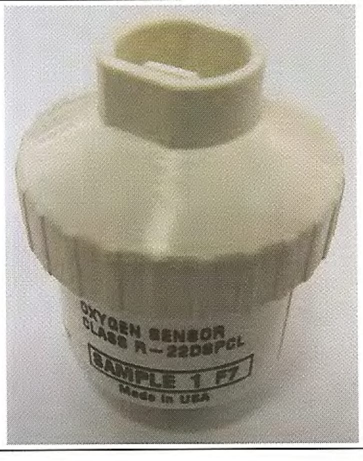
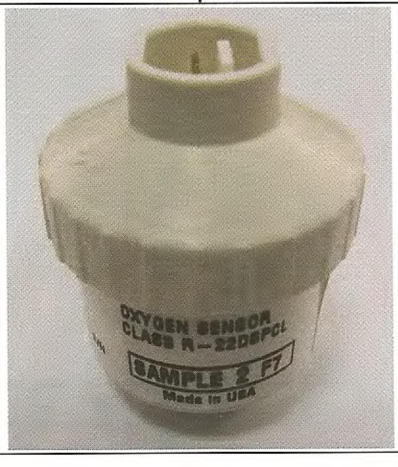


Fig 3-5: Fresh B7 sensor output during 3m drop tests.

During the 3m drops on to a hardwood board with a thick metal plate beneath, an initial decrease in the output signal was registered. The total decrease was 3.1mV or 31% of the initial value. There was no audible noise when the sensor was shaken, indicating there is nothing loose inside the sensor.

4. Test Results for Sensors from Batch F7

Three sample sensors were received from Teledyne with a design change intended to improve the mechanical robustness of the product. These sensors are shown below. They are marked as Type R-22D OXYGEN SENSORS, DATE CODE F7, and as Samples 1, 2 and 3: there is no production serial number on these sensors.

Sample 1	Sample 2	Sample 3
		

4.1. Hard Drop test from 1.5m and 3m with sensors from batch F7

Table 4: 1.5m drop test with F7 sensors

Drop №	before the tests	1	2	3	4	5	6	7	8	9	10	mV drop	% drop
Sample 1 ouptut	9.9	9.9	10.0	9.9	9.9	9.7	9.6	10.0	9.9	9.9	10.3	0.4	4%
Sample 2 output	11.1	11.1	11.1	10.4	10.7	10.8	10.4	10.2	10.2	10.2	11.0	0.1	1%
Sample 3 output	11.1	11.4	11.6	11.3	10.9	10.6	11.3	11.6	11.5	11.2	11.2	0.1	1%

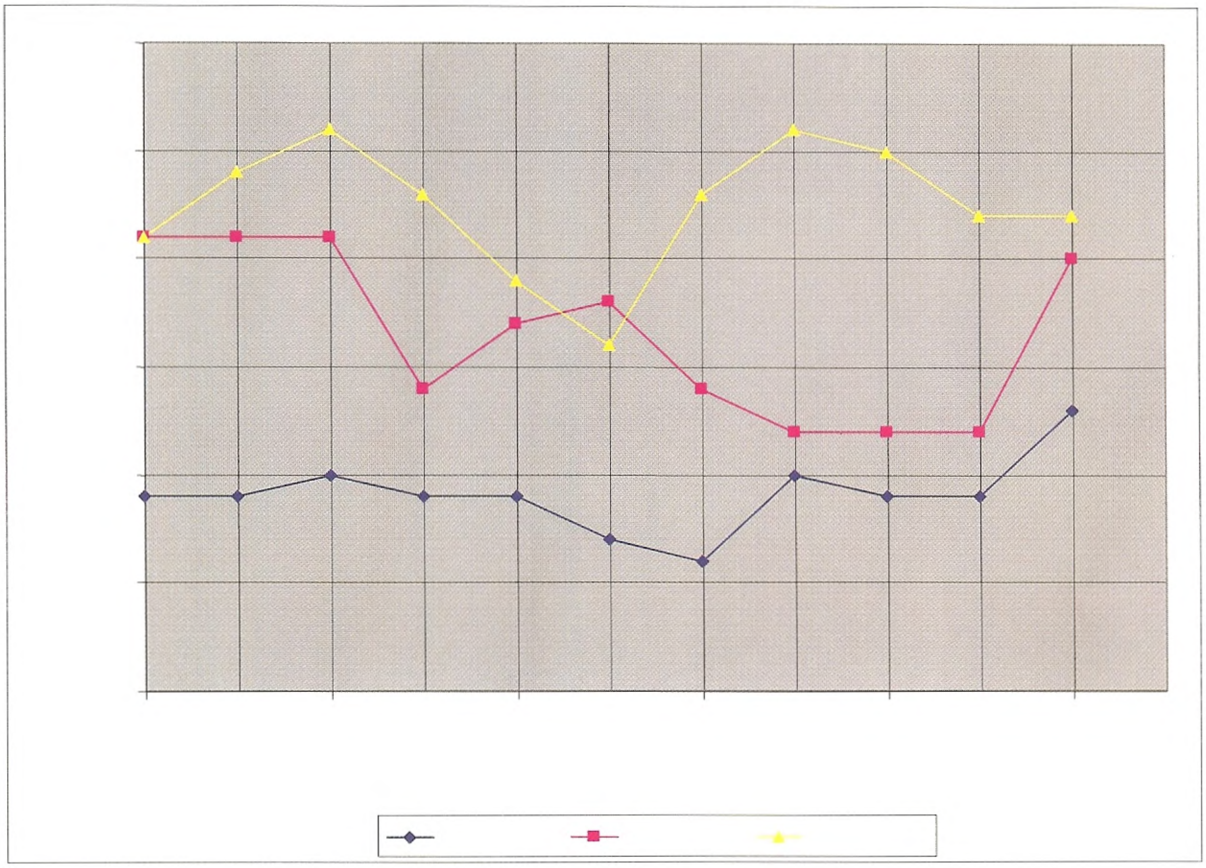


Fig 4-1-: F7 sensor output during 1.5m drop tests.

4.2. 1.5m drop tests revealed that the output signals of the F7 sensor were more stable than those of the B7 sensors. Variations in the sensors' output were caused by random noise from temperature, pressure, electrical noise. A slight knocking sound when the sensor was shaken lightly was noticed after the first drop for Sample 3, after the fifth drop for Sample 2 and after the tenth drop for Sample 1 (the corresponding cells are marked in light blue in Hard Drop test from 1.5m and 3m with sensors from batch F7

Table 4).

Table 5: 3m drop test with F7 sensors

Drop №	before the tests	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	mV drop	% drop
Sample 1	10.2	10.1	10.2	10.0	9.6	9.8	**9.6**	**9.6**	**10.4**	**10.1**	**10.5**	**10.5**	**10.6**	**12.1**	**11.1**	**11.0**	0.8	8%
Sample 2	10.9	11.6	11.2	10.8	11.2	11.2	**12.5**	**12.6**	**12.3**	**12.1**	**12.4**	**13.7**	**11.2**	**16.4**	**19.8**	**19.9**	9.0	83%
Sample 3	11.3	11.2	11.1	11.3	11.5	11.1	**10.5**	**12.2**	**12.0**	**12.0**	**12.1**	**12.0**	**11.7**	**11.3**	**11.4**	**11.3**	0.0	0%

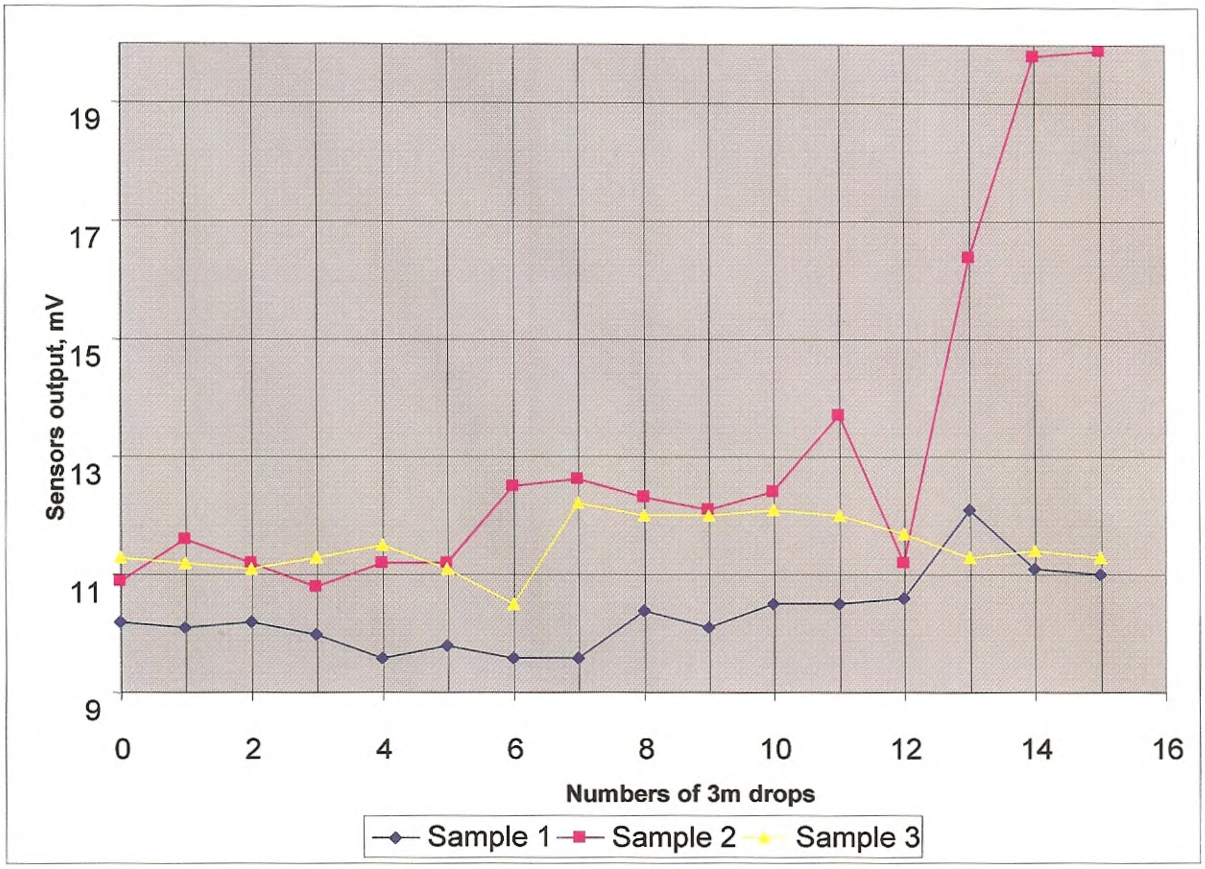


Fig 4-2: F7 sensor output during 3m drop tests.

The Batch F7 sensors were dropped 5 times on to a hardwood surface from a height of 3m. The wooden board was then laid on a thick metal plate and the test was continued (see the bold font results in

Table 5). After the sixth drop, a 'hammering' noise was heard from Sample 1 when it was held by its connector side and shaken. After the tenth drop, loud 'knocking' sounds were heard from Sample 2 when it was shaken. Small signs of electrolyte were also noticed on the body of the Sample 2 (Fig 4-3). After the drop test, the sensor was laid on a slope and small amount of electrolyte dripped out (Fig). The hydrogen ion exponent (pH) of the electrolyte drops was about 14.

The sensor outputs were more influenced by the 3m hard drops on to the wooden board when it had the metal plate below it than without the metal plate. The output of Sample 2 changed by about 83% and there was electrolyte leakage. After two days, its output stabilized at 20mV with some noise variations.

The output of Sample 3 had a small peak increase of 1.7mV and then showed a decreasing tendency. After two days its output was 10mV, with some noise variations due to ambient pressure, humidity and temperature.

The output of Sample 1 showed an increasing tendency. The change in its output was about 8%. After two days its output was 12mV, with some noise variations.

Fig 4-3: Electrolyte drops marked in red on the body of Sample 2

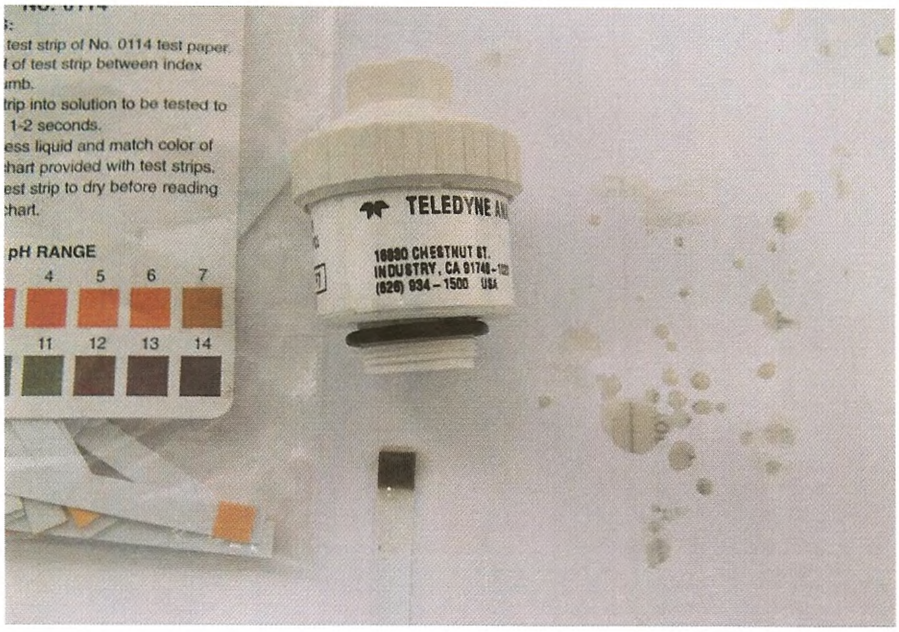


Fig 4-4: Electrolyte drops from Sample 2 after shaking above a paper. Litmus indicator shows pH 14 when moistened with the drops. Electrolyte continued to leak after the tests, and 2 months later the sensor appeared to be dry.

5. Conclusions

The F7 batch of R22 sensors from Teledyne are significantly more robust than earlier batches, and meet the operational requirements for mechanical robustness for rebreathers.

Users should use gloves to replace sensors, or be aware there is a hazard from the LiOH solution.

The next step would normally be to procure a batch of 12 sensors to rerun the other O2 sensor tests in the component safety assessment. Consideration should be given to whether it is economic to run these tests with the R22. The R22 is in products that are in production and that are being released in 2007, but for next year customers are demanding a smaller product, and the K1D type has been selected to comply with that in the next generation of products.

As the K1D sensor is now being designed into products with target release in 2008 and 2009, if Teradyne can apply the improvement in the F7 sensors to the K1D, and confirm these can be supplied with an SMA Male connector instead of the two pins, then the K1D should be adopted for this test programme, either in parallel or as an alternative to the R22-D.