Engineering approach (reliability analysis, metrology and environmental testing procedures) for newly developed marine sensors

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Abstract—
The EU NeXOS project engineering outputs show that once successful and reaching TRL > 7 [], the sensor cost is highly dependent on the mechanical parts, then, the production cost only diminishes with very large production. And, the loss of equipment is in many cases induced by mechanical failures. In the EU NeXOS project, some design and test principles have been promoted in order to minimize at its maximum such failure.

A functional analysis determined the testing requirements for some NeXOS sensor systems to assess robustness. Preliminary testing on mechanical prototypes or complete instruments was conducted under the conditions expected during the sensor life-time. Such testing conditions have been addressed by the 2013 version of the French Standard AFNOR NF X 10 812 [7]. These tests under simulated condition include shock, vibrations, thermal shock and pressure cycling.

A reliability analysis of four use cases related to the three NeXOS sensor systems and two transverse innovations (antifouling and sensor interface) has been performed to validate the increase in TRL achieved during the EU NeXOS lifetime development phase. The reliability of an item or a system can be thought, as a first approach, as the probability that the device or the system will adequately perform the specified function for a well-defined time interval in specified environmental conditions. Starting from this first definition it is well clear the importance of the probability and statistics science in both reliability definition and evaluation. FMEA (Failure Mode and Effect Analysis) is traditionally used for manufacturing process and design, this approach was recommended to be adopted for NeXOS reliability, furthermore the criticality analysis (FMECA) achieved ranked each potential failure mode according to the combined influence of its severity classification and probability of failure based on the best available data. Combining failure analysis results with mechanical data, electrical test data, and production process in-line metrics can provide key information about failure mechanisms. Analysis of yield loss in the production or design line is important to understanding early life failure mechanisms as well as steady state failure.

The robustness of the sensor systems in the EU NeXOS project have been addressed throughout the design and development phase of the project, that is to say the first 39 months. The tests towards environment conditions were defined and performed mostly according to the standard NF-X-10-812. Some other assessments of mechanical designs were also performed such as computation of stresses under external pressure. Relevant metrology assessment was performed in order to initially qualify the metrological performance of the sensors and to periodically test the sensors during the tests towards environment conditions.

.Keywords—subsea sensors; fouling protection; sensor systems; reliability; oceanographic sensors .

I. Introduction

While transduction and metrology performances are the key to a successful sensor, its impact on science is funded on its capacity to work in various conditions. Modern in-situ sensors are working unattended and launched on board automated platforms facing harsh conditions. This is the reason why the same design and qualification methods, as those used for costly underwater platforms (submersibles, ROVs, AUVs, etc.), must be used for sensor and instrument design and qualification. This is not trivial at first because the budgets allocated to mechanical design are not of the same order of magnitude than those involved in large structures.
An example of the engineering method applied in the NeXOS project is presented here. Among the dozen of sensor systems developed in the project, 4 use cases were defined to apply the full method. One of them is presented with more details.

II. USE CASES

Due to the large number of NeXOS products and their versatility to be mounted on several platforms, RAMS (Reliability, Availability, Maintainability and Safety) and other reliability assessments cannot be performed and discussed on all the configurations. The use cases were chosen in order to cover several NeXOS products from all sensor types addressed in the project: passive acoustic, optical sensors and probes for the Ecosystemic Approach to Fisheries (EAF). The platforms are diverse: Argo float, ship of opportunity (fishing vessel), fixed observatory and glider.the arguments for the choice are the availability of operation data and maturity (TRL) of platforms, the maturity of sensors (TRL>7) and the tests towards environmental conditions performed in the context of NeXOS.

	Innovative products	Test NF X 10812	TRL (targeted)	Platform	TRL (platform)	RAMS background
Use Case 1 – A1 on PROVOR float	A1	Yes	8	ARGO Float	9	Argo float database
	SensorML software		8			
Use Case 2 – EAF oxygen and fluorescence probes	EAF1and EAF2	Yes	7	Ship of opportunity	9	Recopesca maintenance database
	Recopesca system		9			
Use Case 3 – Antifouling system on Trios sensor	Antifouling	Yes	7	Fixed point observatory (COSTOF2 based)	8	Limited EMSO data
	Former Trios microFlu-chl sensor	Yes, similar standard for new sensor MatrixFlu	9			
Use Case 4 – Protected Minifluo on SeaExplorer glider	Antifouling protection		7	Glider	9	GROOM publications on gliders [3], [4]
	Optical sensor O1	Yes according to other standard	7			

Table 1 – Choice of Use cases representative of the developments of NeXOS project.

The Use Case 1 will be presented more precisely in this paper.

III. METHOD USED FOR FMEA

. The Failure Modes and Effects Analysis (FMEA) methodology.is used as a starting place. Major focus of an FMEA is to identify the items where modification to the design or the operating, inspection, or maintenance strategies may be required to reduce the severity of the effect of specific failure modes. It can be performed to meet a variety of different objectives, for example, to identify weak areas in the design, the safety-critical components, or critical maintenance and test procedures. Anticipating these failure modes, being the central step in this analysis, needs to be carried on extensively, in order to prepare a list of maximum potential failure modes. At our stage in NeXOS of assessing innovative sensor technologies immediately at the validation phase a limited quantity of information is available

There are two basic approaches, known as functional and hardware FMEAs, described in MIL-STD-1629-A [2]:

1. The functional FMEA is normally used for complex systems in a top-down approach where the system is successively decomposed down to sub-system and equipment level depending on the information available and the objective of the analysis. Sub-assemblies/equipments are treated as 'black boxes' providing some required function in the system. The reliability engineer considers the effect of loss of inputs (e.g. essential supplies) and sub-assembly/equipment failures on the functional performance of the system. Its main application has been to identify and classify equipment according to the severity of their failure modes on system operation. It is frequently employed as a precursor to a more detailed FMECA or fault tree analysis.
2. The alternative is a hardware (bottom-up) approach where each component of the system is considered in isolation for each of its physical failure modes to establish the likely effect on system operation.

For NEXOS the first approach was used and the analysis were extended to include failure rates or probabilities as well as severities to become an FMECA - a failure mode and effects criticality analysis.

A criticality assessment is an attempt to identify and prioritize failure mode importance as a function of the severity of the effects at system level and the probability of occurrence. The fuzzy prioritization of failure modes appears to be the best method currently available for supporting the developments in NeXOS to make the FMECA more confident than perceptual.

Fuzzy Logic

The fuzzy logic approach is significantly more involved than other criticality analysis techniques, it is considered to have several advantages compared with qualitative or strictly numerical methods [10].

Fuzzy logic provides a tool that can be used throughout the design process for performing a criticality analysis on a system design and prioritizing the failures identified in a FMECA for corrective actions. This approach resolves some of the problems in traditional methods of evaluation and it has several advantages compared to strictly numerical methods [3]:

1) It allows the analyst to evaluate the risk associated with item failure modes directly using the linguistic terms that are employed in making the criticality assessment;

2) Ambiguous, qualitative, or imprecise information, as well as quantitative data, can be used in the assessment and they are handled in a consistent manner;

3) It gives a more flexible structure for combining the severity, occurrence, and detectability parameters.

A fuzzy logic criticality assessment is based on the severity, frequency of occurrence, and detectability of item failure modes. These parameters can be represented as members of fuzzysets, combined by matching them against rules in a rule base, and then defuzzified to assess the risk of failure.

The linguistic variables used in NEXOS to describe the parameters involved in the analysis are shown on Tables 2 and 3. They show the criteria used to rank the severity of the failure effects, and describe the range of values and the linguistic terms used to rank the frequency of the failure mode occurrence and the used risk rule template. This risk rule template could be filled in as often as necessary, depending on system, subsystem, failure mode, etc.

Severity fuzzysets	*Seriousness of the failure mode effect on the next higher level assembly and the system*
Low	Unreasonable to expect any real effect on system performance / Slight deterioration of system performance
Moderate	Noticeable degradation of system performance
High	Change in operating state but does not involve safety/ Affects safety of system and/or environment

Occurrence fuzzysets	*Relative number of failures anticipated during the design life of the item. Range of values used to rank the frequency of the failure mode occurrence*
Low	Failure probability < 1 in 4000
Moderate	Failure probability between 1 in 1000 and 1 in 40
High	Failure probability > 1 in 20

Detectability fuzzysets	*Ability of a proposed design verification programme to identify a potential weakness before the component or assembly is released to production*
High	Almost certain to detect design weakness / Good chance of detecting design weakness
Moderate	May not detect design weakness
Low	Design weakness probably not detected / Very unlikely to detect design weakness

Risk importance
Unimportant
Minor
Low
Moderate
Important
Very Important

Table 2. Risk Rules Definitions

Rule	Ocurrence	Severity	Detectability	Risk
1	Low	Low	High	
2	Low	Low	Moderate	
3	Low	Low	Low	
4	Low	Moderate	High	
5	Low	Moderate	Moderate	
6	Low	Moderate	Low	
7	Low	High	High	
8	Low	High	Moderate	
9	Low	High	Low	
10	Moderate	Low	High	
11	Moderate	Low	Moderate	
12	Moderate	Low	Low	
13	Moderate	Moderate	High	
14	Moderate	Moderate	Moderate	
15	Moderate	Moderate	Low	
16	Moderate	High	High	
17	Moderate	High	Moderate	
18	Moderate	High	Low	
19	High	Low	High	
20	High	Low	Moderate	
21	High	Low	Low	
22	High	Moderate	High	
23	High	Moderate	Moderate	
24	High	Moderate	Low	
25	High	High	High	
26	High	High	Moderate	
27	High	High	Low	

Table 3 - Risk Rules Template

For the fuzzy logic method used on each case, the evaluation criteria are represented by distributions which overlap (low-Moderate-High) as shown on Figure 1.

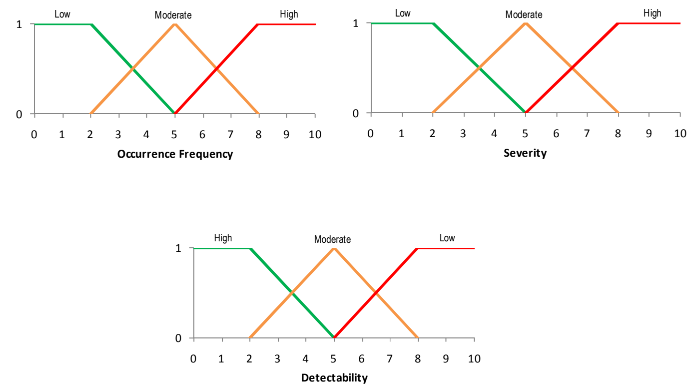

Figure 1 - Fuzzy Logic Overlapped Distributions

Engineering judgement estimations for occurrence frequency, severity, and detectability are taken from the appropriate tables and entered into FMECA worksheets. The fuzzification process converts occurrence frequency, severity, and detectability inputs into outputs which can be matched to rules in a rule base.

For example, given a failure mode "A" with values attributes for occurrence frequency (3), severity (7) and detectability (8), the membership of each attribute set can be determined from the distributions in Figure 1, as shown in Figure 2.

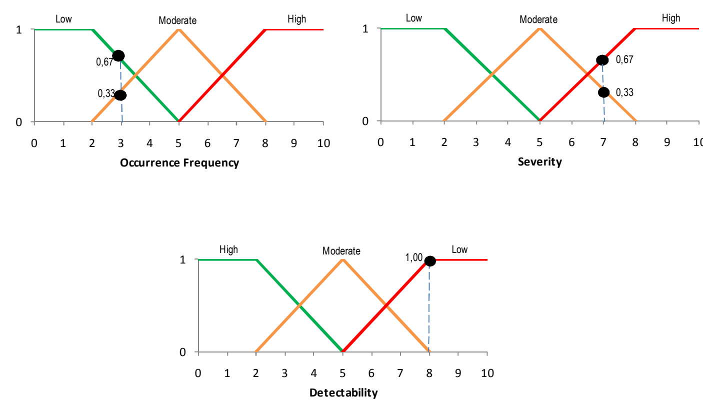

Figure 2. Value Attributes (Example)

The rule base describes the risk to the system for each combination of the input variables. They are formulated in linguistic terms as IF-THEN rules which are implemented by fuzzy conditional statements. For example: IF frequency is Low, severity is Moderate, and detectability is Low-to-Moderate, THEN risk is Moderate. For example, given the rule base Table for a the previous failure mode "A,"

Rule	Frecuency Occurrence	Severity	Detectability	Risk
6	Low	Moderate	Low	Moderate
9	Low	High	Low	Moderate
15	Moderate	Moderate	Low	Moderate
18	Moderate	High	Low	Important

Table 4 Risk Rule (Example)

The consistency of the rule base used for assessing criticality can be defined by examining a plot of the risk surface over all possible combinations of the input variables as shown in Figure 3.

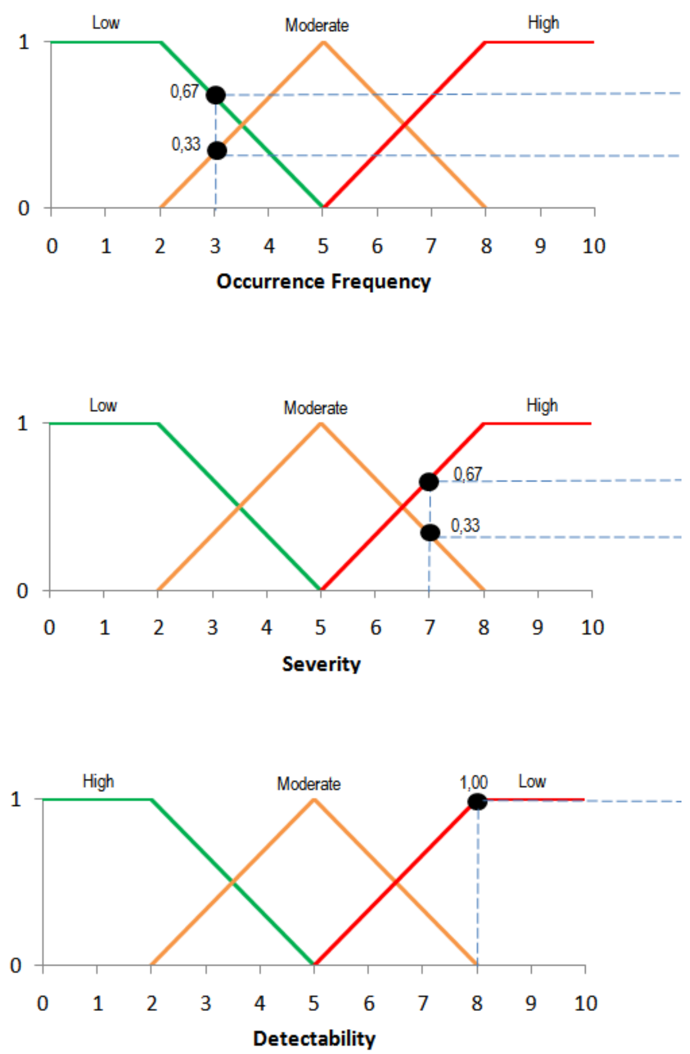

Figure 3 - Fuzzy Inputs (Example)

The outputs for assessing risk importance can be defined using fuzzy sets in the same way as for the fuzzy inputs. The fuzzy inference process uses a 'min-max' approach to calculate the rule conclusions based on the input values. The outcome of this process is called the set of fuzzy conclusions.

The 'truth' value of a rule is determined from the combination of the information associated with each rule. This consists of determining the smallest (minimum) rule antecedent, which is taken to be the truth value of the rule. If any fuzzy output is the consequence of more than one rule, as shown in the example, then that output is set at the highest (maximum) truth value of all the rules that include this as a consequence. Hence, the result of the rule evaluation is a set of fuzzy conclusions that reflect the effect of all the rules with truth values greater than a defined threshold.

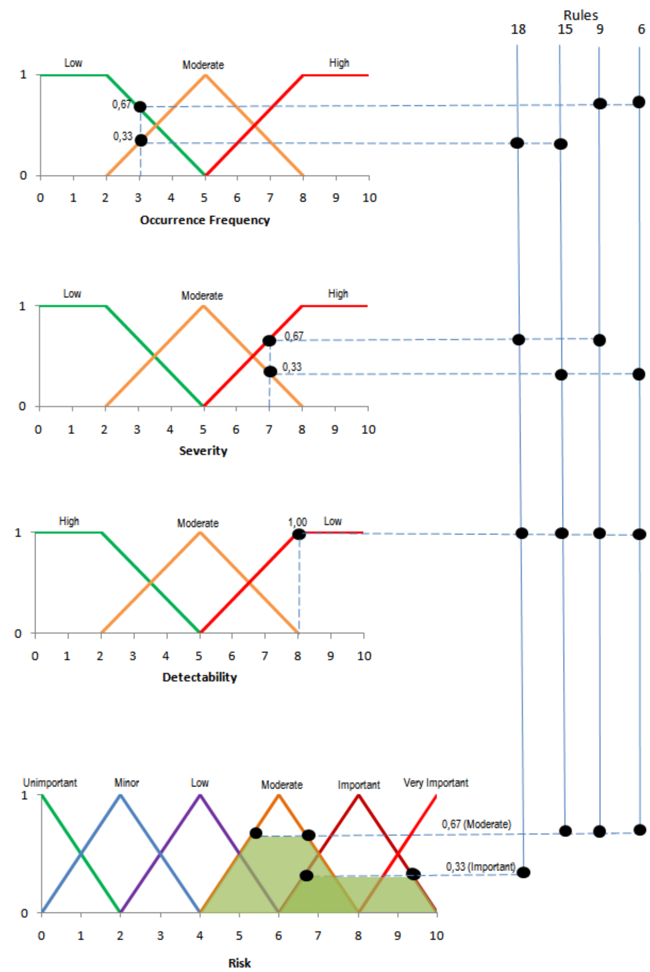

Figure 4 - Rule Evaluation (Example)

Finally, the defuzzification process creates a single crisp ranking from the fuzzy conclusion set to express the inherent risk Figure 4.

Several defuzzification algorithms have been developed of which the weighted mean of maximums (WMoM) is probably the most commonly used. This method gives a best-estimate of the average, weighted by the degree of truth at which the membership functions reach their maximum value:

$$\mathrm{WMoM} = \frac{\sum w_i x_i}{\sum w_i}$$

$w_i = degree\ of\ truth\ of\ the\ membership\ function$
$x_i = risk\ rank\ at\ maximun\ value\ of\ the\ membership\ function$

This WMoM value represents the inherent risk of the failure mode on a scale **0**-10. Criticality ranking of failure modes will be in decreasing order of risk importance.

FMEA and fuzzy prioritization of failure modes in NEXOS were done using CEANI (ULPGC) tools and the completed FMECAs (failure mode effects and criticality analysis) were established for the use cases listed in Table 1.

IV. HYDROPHONE A1 ON PROVOR FLOAT

A1 hydrophone

A1 is designed and built by SMID in NeXOS project. It is a compact, low power (<1W) multifunction passive digital sensor, enabling acoustic measurements and characterization of underwater noise and several soundscape sources; A1 is mainly designed to be used on mobile platforms, with limited autonomy and/or limited communication capability.

Figure 5 - Acoustic Sensor A1

A1 consists of one hydrophone and two A/D converters, simultaneously sampled, with different gain to detect, in the same time, acoustic source levels from 50 dB to 180 dB re 1µPa in the frequency range from 1Hz to 50kHz.
The signals are sampled by two 16-bit SAR converters controlled by an ARM microcontroller that takes care of proper data processing (mathematical operations).
In order to avoid aliasing problems a switched capacitor filter digitally controlled by the Micro Controller Unit (MCU) has been added in the chain after the amplifier stage.
The MCU processes the sampled data and transmits the results on a EIA RS-232 serial port.
A1 sensor is composed of:

- One Hydrophone Sensor (HYD) of different types
- One Signal Conditioning Unit (SCU) including: low power, low noise CMOS preamplifiers, Equalizer, Anti-aliasing filters
- One Micro-power SAR Analog to Digital Converters 16 bit ADS8867 (2 Ch.)
- One MicroController Unit (MCU) LPC4370
- Underwater connector

A1 is innovative in many ways. It benefits nevertheless from the experience of moulded hydrophones, operated since the 80's in the deep sea. The early versions of RAFOS floats integrated already hydrophones helping the positioning of the floats among sound sources by triangulation [9], [10]. The hydrophones were built by Benthos, Pons and other companies.
The principle to use an industrial connector (for A1, SMID uses a Subconn MCBH12M) as a basis has been used by these manufacturer, following bad experiences in earlier designs. A great advance is coming from the miniaturization of the analogic to numerical conversion and its integration inside the hydrophone. Then, the connector, always a weak point in underwater systems, is transmitting numerical signal, without the perturbations induced when the connectors were transmitting analogic signal.
The high pressure resistance, water tightness and the ageing are ensured by plastic moulding. Again, this is a classical practice on hydrophones, proven by decades of military, research and industrial underwater acoustics applications. SMID uses two moulding phases: epoxy resin directly on electronic boards, polyurethane, ensuring water tightness while acoustically transparent. These material solutions are optimizing the performances with respect to former neoprene moulding. Anyway, moulding is a unitary process which requires unitary pressure testing to track potential microbubbles, motion in cable connections or micro-seeps.

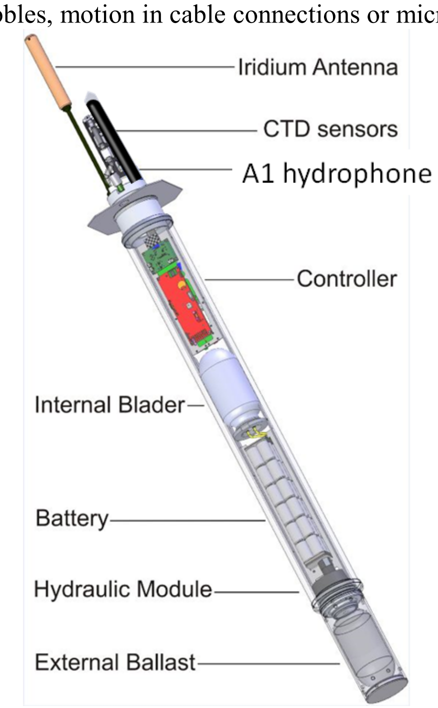

Figure 6 - ARVOR and PROVOR float components

PROVOR floats are part of the industrial offer for the ARGO international research effort [11] to monitor the first 2000m of the world ocean by more than 3500 profiling floats cycling weekly. ARGO floats are measuring temperature, conductivity and pressure. Dissolved oxygen is becoming an additional parameter for a few hundred floats.

Among the 6354 floats deployed between 2008 and 2014, 590 PROVOR floats have been operating under ARGO cycling standards (Figure 4.3). They have been replaced in the nke offer by ARVOR model more optimized towards these standards.

Initially dedicated to the measurement of temperature (Seascan sensor) or conductivity/temperature (Falmouth Scientific or Sea Bird sensors) for the need of operational oceanography, PROVOR turns towards a new vocation: a multi-sensor platform designed for the new expectations of the oceanographers. PROVOR CTS3 is a platform able to carry **various sensors**. Among them a PROVOR-A includes a RAFOS acoustic location hydrophone which allows positioning of the float during its drifting [10].

PROVOR profiling floats are built by nke under Ifremer license.

A PROVOR float is a 2000 m water depth rated (test pressure with 1.1 coefficient, meaning a metal enclosure of class C according to NF X 10 812) autonomous system. It is composed (Figure 6) of several subsystems: antena for satellite transmission, CTD sensors, additional sensors (in our case A1), floatation foam, magnet for on-off and bluetooth, main electronic board, CTD electronic board, battery pack, internal bladder, external bladder/ballast, pump, motor and electro-valve, lest and bladder protection, hard anodized aluminium housing.

A quantity of oil is transfered from the external bladder to the internal bladder by an electro-valve and from internal bladder to external bladder by a high pressure pump moved by an electric motor. As oil has a lower density than seawater, it modifies the Archimede buoyancy force (bringing oil at the outside means provide additional buoyancy, retrieving it lowers the buoyancy) on the whole float respectively downward and upward.

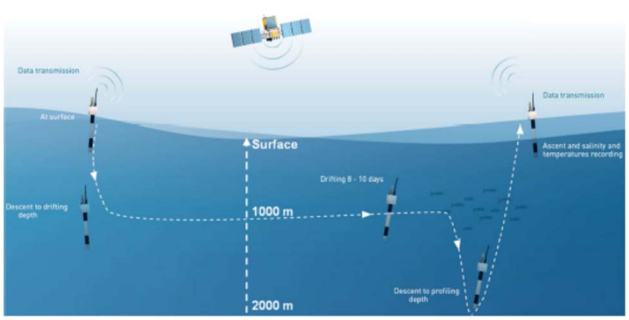

Figure 7 - ARGO profiling float cycles

Electronic interface

PROVOR is a valuable product for nke as far as new sensors can be interfaced . This is done by a dedicated electronic board already used for PROVOR-A, PROVOR BIO, PROVOR BIO 2, PROVOR CARBON, PROVOR ULS (under ice conditions). It is used now for NEXOS demonstration.

Software for SensorML compliance

The interface software developed by NeXOS is implemented in the PROVOR integration of A1.

Simulated tests towards environmental conditions

The **PROVOR floats** were qualified according to NF X 10 812 1995 version using a coefficient test pressure / service pressure of 1.1 instead of 1.2 at that time. The 1.1 coefficient proved efficient for an underwater system neither interfering with other platforms nor with human occupancy vehicles. It was introduced in the 2013 version of the NFX 10 812 standard as the coefficient for metal enclosures of class C. During this qualification test, the temperature is low (2°C). It is followed by 10 cycles at service pressure.

The level of quality requires a unitary testing program ("validation"). After manufacturing, all floats are pressure tested at a testing pressure of 1.1 times the service pressure at ambient temperature during 1h. Then they are cycled during a functional test at 20m water depth. The cycle includes: diving, measurements, ascent and data transmission.

The **A1 hydrophones** have been tested by Ifremer according to designer's request as part of NeXOS.

Hydrophone A1 JS-B100 has been tested for class B severity level according to NF X 10 812:

Hydrostatic pressure leading to qualification for a service pressure of 308 bar (3000 m water depth).
One cycle of 8h at 2°C under 370 bar. Speed 12 bar/mn.
10 cycles of 1 h at ambient temperature and service pressure.
Storage under heat leading to qualification.
96 h under 50°C and 93% moisture.
Storage under cold conditions leading to qualification.
72 h at -20°C
Vibration test leading to qualification.
No research of eigen-frequency on this type of monolithic equipment. Frequency bands are covered during one hour at a speed of 1 oct/mn from 1 to 16 Hz with an amplitude of 1mm and from 16 to 55 Hz an acceleration of 10 $m.s^{-2}$.
Mechanical shock tests leading to qualification through two operating modes:
- Operating mode 1 of the standard: 3 half sinus shocks in the 3 directions both ways (means 18 shocks)
- Operating mode 5 of the standard: along one of its side, the hydrophone is lifted 45° and falls on a plank of wood. The number of falls is limited to 4 per side and 8 in total. As the A1 is a cylinder, two falls were performed, one at each end.

Failure data base on ARGO floats

The issue of ARGO float losses is crucial for this large infrastructure of 4000 floats operated worldwide. The major point is that the faulty profiling floats are seldom recovered so that diagnostics are quite rare. This pushed to implement technical parameters and data analysis procedures to follow changes which may signify a potential "illness" of one or a series of floats. This follow up is operational for the European part of the ARGO (EUROARGO) and some other owners. All PROVOR floats are monitored and parameters are accessible in this database.

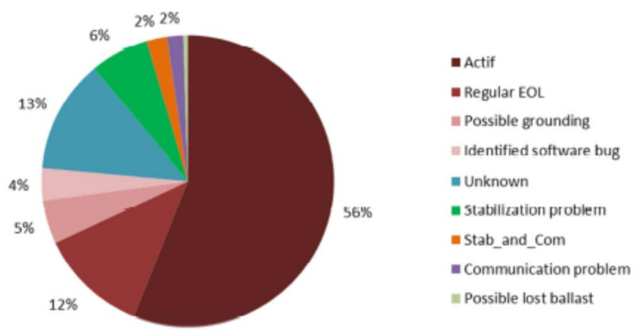

Figure 8 – Status in 2014 of 616 PROVOR floats deployed since 2008. The reasons of failure are reported once the operating parameters transmitted have been analysed (note the 13% of unknown reasons).

The various type of diagnostic (see figure 4.4) are coming from the analysis of transmitted technical parameters and from the detailed analysis of the cycles (mainly the depth data compared with the hydraulic actuations) when anomalies, revealed by the automated or the manual data data quality checking conclude that no Ocean circulation phenomenon can explain the float behavior.

In any case, looking through the data base, there does not seem to be a correlation between the losses and the number of sensor carried by the profiling float. The tens of PROVOR floats equipped with dissolved oxygen optodes and CTD have not suffered more (nor less) misfunctionning than CTD ones during the first 3 years. Statistics will continue to be established and will provide conclusions once reached a sufficient number of floats x km.

FMECA analysis

The procedure explained in §III was applied: a) first by asking experts to give marks in a table (principles in Table 2.2) for the Severity, Probability and Detectability of failure modes ; b) then by self evaluating their point of view by filling in a risk table (principle in Table 2.3); c) ULPGC analysed the evaluations providing the following raw table.

System	ID	Name	Function/Description	Failure Mode	Corresponding life cycle (transport, launching, underwater cycles, surface)	Failure Mechanism	Risk SLR	Risk JFR
A1	1	Hydrophone	Acoustic Sensor	Failure	underwater cycles	Energy Depletion	8	10
					any	Corrosion	4	8
				Intermittent Link Failure	underwater cycles	Excesive Noise	4	7.5
					any	Internal connector misfunction	6	8.66666667
	2	PCB	e analog signal, sampling, converting to digital	Performance Problems	any	Environmental Stress	7.333333333	10
					any but transport	Circuit Desing Problem	8	10
					any but transport	Design misreading	4	7.2
					any but transport	Design mislabeling a component	4	7.2
					any but transport	Manufacturing Issues	5.2	7.2
				Not Output Signal	any but transport	Serial Port Failure	4.8	5.5
					any but transport	Input Failure	4.8	7.2
					any but transport	Main Power failure	5.5	8.66666667
					any but transport	Circuit failure	6.666666667	10
				Interface electronic board in the Float fails	any but transport	Circuit failure	6.5	9.33333333
				Error in data transmission after encoding	any but transport	Sensor ML software misfunction	8	10
	3	Moulding and connector	Water tightness	Link failure with float	any	Link Breakage (mechanical)	8	10
					any	Leakage of connector o-rings	9.333333333	10
					any	Electric failure of connector	9.333333333	10
Float	4	roprocessors and control softw	deal with function control and scheduling	Software loops	underwater cycles	Failure on cycle timing variables	4	8
				Sequencing failure	underwater cycles	Abnormal chronological order of timing events	6	6
				Datastorage failure	underwater cycles	Lost Data	4	8
	5	Data transmission system	controls communication with satellite	Lost data	transport, launching, surface	External Shock on Antena	4.666666667	8.66666667
				Transmision failure	transport, launching, surface	Circuit board failure	4.666666667	8.66666667
				Transmision failure	transport, launching, surface	Insuficient Power imput	8.666666667	10
	6	Hydraulics	nent via an inflatable external bladder, so the f	Mismatch of commands	underwater cycles	Abnormal chronological order of timing events	5.333333333	9.33333333
				Lost Stability	underwater cycles or surface	Leak on Bladder	5.333333333	9.33333333
					surface or launching	Damage on stability disk	1.333333333	2.66666667
				Hydraulic Pump failure	underwater cycles	Hydraulic Pump failure	4	8
					underwater cycles	Motor Failure	4	8
					underwater cycles	Internal leak of Hydraulic fluid	7.6	9.33333333
				Hydraulic valve failure	surface or launching	Electromagnet failure or piston blocked	8.666666667	10
	7	Standard Argo sensors	Measures depth	Wrong reference depth for all data	underwater cycles	Misfunction of sensor	6.5	6
				Ascent or descent cycles are wrong	underwater cycles	Failure of sensor	8	10
			Measures Conductivity and temperature	Argo data unavailable	underwater cycles	Misfunction of sensor	7.333333333	8.66666667
				False data	launching or surface	Shock on sensor subsystem	8	10
	8	Main pressure housing	otects the components at atmospheric pressu	Loss of buoyancy	underwater cycles	Leakage of o-rings	4	8
					underwater cycles	Hull buckling	4	8
	9	Li - Batteries	Provide power	Premature end of cycling	underwater cycles	Misfunctioning of elements	8	10
					transport	Water ingress	8	10

Table 5..- FMECA Analysis of use case Hydrophone A1 on PROVOR Float

Results on the Use Case

- Shock testing is not relevant on moulded hydrophones such as A1. A recommendation in order to reach TRL8 would be to design a transport box which will protect A1 hydrophones and PROVOR floats when mounted together. This will ensure a safe delivery over the final phase of launching from a ship.

- This device has one predominant failure mode: “Link failure with float”. This failure mode has three failure mechanisms: Link Breakage (mechanical), Leakage of connector o-rings, Electric failure of connector. Connectors are systematically weak points in subsea systems. In this case, the unitary test at low pressure of the whole Float-hydrophone assembly is needed. It is a EUROARGO practice.
- On the hydrophone, it is remarkable to mention a failure due to energy depletion and an intermittent link failure due to internal wiring connection misfunctions. This is often the case when a moulding is performed around a wiring link. Unitary tests before launching do reveal this type of manufacturing fault.

The addition of an A1 hydrophone does not change the overall reliability of the Argo float, except for the new interface and modified electronic board and software.

V. CONCLUSION

Within NeXOS project, methods have been applied to design according to Technology Readiness and Reliability indicators. Such approach suffers usually from lack of input in oceanography. Tests towards environmental conditions [6] [7] must be systematic. The establishment of failure data bases on instrument fleets such as ARGO floats, RECOPESCA [8] or gliders [4] [5], open the way to a ranking of failure modes. This is profitably completed by FMEA analysis using fuzzy logic approach as demonstrated for 4 use cases of NeXOS newly developped sensors interfaced on various platforms. Then, failure modes can be ranked before the deployment phase, helping to focus attention during the critical exercise of validation at sea.

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