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Reliability centered modeling for development of deep water Human Occupied Vehicles

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ABSTRACT

Human Occupied Vehicle operations are required for deep water activities such as high resolution bathymetry, biological and geological surveys, search activities, salvage operations and engineering support for underwater operations. As this involves direct human presence, the system has to be extremely reliable. Based on applicable standards, reliability analysis is done on 5 key representative functions with the assumption that the submersible is utilized for ten deep water missions per year. Analysis is done on the results obtained to find the influence of the subsystems on the reliability of the overall submersible. Analysis include, influence of battery technologies and reliability centered battery and hydraulic system configurations. Dependence of seal sizes and seal seat surface finish on the leak tight integrity of the personnel sphere is also discussed. It is found that for submersible housing 75 kWh energy storage batteries, the probability of failure of the hard tank buoyancy ascent function with lead acid batteries configured for 300 V terminal voltages and non-redundant hydraulic configuration is 37.74%. The probability of failure can be reduced to 5.24% with lead acid batteries with terminal voltage configured to 120 V and with redundant hydraulic configuration. The results presented shall serve as a model for designers to arrive at the required trade-off between the capital expenditure and the required reliability.
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1. Introduction

Human Occupied Vehicles (HOVs) are useful tools for the researches investigating deep sea life and for exploring ocean resources. Even though unmanned vehicles have improved maneuvering capabilities and excellent vision systems which resemble direct observation, HOVs provide a feel of direct physical presence for the researches. The successful operation of the first generation HOV, Trieste [1,2] at a water depth of 10,906 m in the Mariana Trench triggered initiatives for the development of more efficient HOVs. Further technical developments have greatly expanded the operating range and improved the operational efficiency of the HOVs used in scientific research. The second generation HOV which is centered on the development of a lighter hull for the crew, improvement of the power supply for propulsion, and establishment of reliable systems, include Alvin [3] of USA, Nautile6000 of France, Shinkai6500 of Japan [4], MIR 6000 submersibles of Russia and Jiaolong 7000 of China, developed during the period since 1964 [5].

With the experience gained in the development and successful qualification of deep water unmanned Remotely Operable Vehicle ROSUB 6000 [6–9], the National Institute of Ocean Technology with the objective of augmenting India's capability in deep sea research, is planning to develop a HOV capable of operating in deep waters and used for carrying out scientific exploratory activities [8,10].

As HOVs are not electrically powered from the surface, they require self-contained power supply with high energy storage [2] which increases the weight and volume of the submersible, which in turn limits its operational endurance. When a human is in the system he/she must be protected from the hostile deep water environment, and hence, the reliability of the system is of utmost importance [11]. This calls for man-rating certifications, and is done by bodies including the American Bureau of Shipping (ABS) [17], Germanischer Lloyd [18], Det Norske Veritas (DNV) [11] and operational guidances by International Marine Contractors Association (IMCA) [19].

This paper reviews the recent technological developments in the systems required for reliable operation of deep water HOV. Based on the applicable DNV guidelines RP-203 for qualification procedures for new technology [12] reliability analysis are made on the five identified key representative HOV functions, with the assumption that the HOV is utilized for ten deep water dives per year, each deep water mission clocking 4 h of subsea operation. Studies were carried on the results obtained to find the subsystems influence on the overall submersible reliability and it is found that energy storage batteries and hydraulic systems are major contributors in

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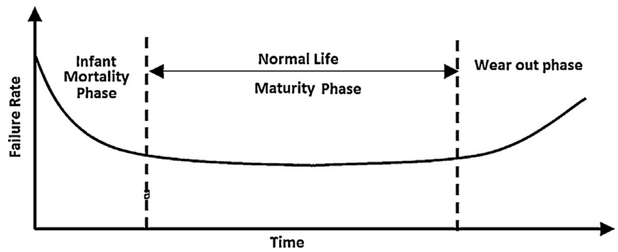

Fig. 1. Reliability bath tub curve indicating the life cycle [13].

deciding the HOV operational reliability. A detailed analysis on the influence of battery chemistry, battery architecture, and hydraulic architecture and personnel sphere seals is presented.

2. Major standards followed for reliability modeling

The following is the major list of standards followed:

(1) FIDES Guide for the estimation of Reliability [13] for electronic components and systems, considering mission and environment specific analysis.
(2) MIL HDBK 217F, Military handbook for Reliability Estimation [14] of Electronics Equipment.
(3) OREDA Handbook [15] for Offshore Reliability Data.
(4) IEEE 493 IEEE Recommended practice [16] for Design of reliable Industrial and Commercial Power Systems.
(5) DNV RP-A-203-Qualification procedures for new technology [11].
(6) Handbook for reliability prediction procedures for mechanical equipment by Naval Surface Warfare Center (NSWC) [20].

The failure rate determination for the system components was done by the following methods:

(a) Based on the manufacturers' data and interpretation according to the mission profile.
(b) For systems where Failure-in-Time (FIT) data are not available, failure rates are calculated from component failure data from the respective standards (FIDES, IEEE, and MIL), taking into consideration the mission profile, operating conditions and operating stresses.

FIDES [13] approach is based on physics and failures, supported by the analysis of test data, feedback from operations and existing models along with statistical interpretations over the normal operating life period of the system and is indicated in Fig. 1.

The provision in the FIDES standard considering the influence of the operating temperature, amplitude and frequency of the temperature changes, vibration amplitude, humidity and operating stresses based on Arrhenius, Norris and Basquin laws [13] was applied for calculations. The provision given for accounting manufacturing and integrating quality factors are also applied. The standards also provide Commercially-Off-The-Shelf (COTS) boards approach for calculating the failure rates of the systems for the defined mission profile with the functional requirements and mission profile as inputs from the user. The failure rate determination for the components is done at the circuit component level, and is incorporated in the reliability trees [23]. Table 1 gives the standards followed for the major systems and components.

Table 2 shows the FIT values of major systems considered for computations. The values are obtained from indicated standards and the values arere-computed based on the actual mission profile and operating conditions adopted.

The TOTAL-SATODEV GRIF tool [21] is used for realizing failure trees.

Table 1
Standards followed for FIT estimation of subsystem components.

Components	Standards
Batteries, Power electronic converters, Transformers, Isolators, Motors, Pumps, Lamps, Cameras	MIL and IEEE
CPU, DC-DC Converters, Fuses, Connectors, Ethernet Converters, Input and Output modules for Data acquisition cards	FIDES
Subsea sensors and transmitters, Solenoid Valves, O-rings, Gaskets	OREDA, NSWC, ABS
Electronic Pressure cases, Personnel Sphere, Entry Hatches, View Ports	ABS, DNV, Germanischer Llyods

3. Overview of HOV systems

Fig. 2 shows the overview of typical deep water HOV [2]. The major systems of the HOV include the pressure rated personnel sphere (PS) for human occupancy, equipped with hatch and view ports. They house the systems required for the control of the HOV, communication aids and life safety systems required for the crew. Electro-optical penetrators enable electro optical communication from the external systems. The propulsion system comprises of batteries and thrusters to enable the vehicle maneuverability in multiple degrees of freedom, variable buoyancy enabling systems comprising of spheres, pumps and compressed air bottles for descend, traverse, and ascend operations, navigation systems for position determination and safe vehicle maneuvering, Ship-HOV

Table 2
Failure-in-time data used for configuration.

Component	FIT (in 10^9 h)
Batteries	
Lead acid battery 12 V, 100 Ah	3140
Lithium ion battery 12 V, 3.8 Ah	237
Control and network electronics	
Real time controller	41
Analog input/Output module	12
Ethernet switch	70
Industrial Computer	527
Vision support systems	
Camera	355
Light	350
Navigational sensors	
Photonic Inertial Navigation Sensor (INS) with Micro-Electro-Mechanical Systems (MEMS) based INS in redundancy	4650
Doppler Velocity Log (DVL)	300
Power conditional systems	
DC–DC converter	75
DC–AC converter	245
Propulsion systems	
Thruster motor electronic controller	477
Thruster Brush-Less Direct Current (BLDC) motor of 8 kW capacity	455
Hydraulic systems	
Pump	5400
Pressure sensor	60
Control valves	341
Others	
Shape memory alloy element	92
Subsea cables	244
Subsea connectors	20

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