DYNAMIC POSITIONING CONFERENCE
October 11 - 12, 2022

THRUSTER SESSION

Navy Submarine Rescue on a DP Vessel

By Liz Hunter

(Oceaneering International Inc.)

Abstract

The U.S. military maintains and operates manned underwater vehicles (MUV) that are used for submarine rescue. The main submarine rescue system is classed by the American Bureau of Shipping (ABS), part of the International Association of Classing Societies (IACS), to ensure safety standards are established and adhered to. The rescue system's concept of operations includes a capable vessel of opportunity (VOO) to serve as a Mother Ship (MOSHIP) where the MUV and its support equipment is installed on the working deck. The VOO has an International Maritime Organization (IMO) Dynamic Positioning (DP) Class Two (DPS-2) requirement, and the military further mitigates risk with additional criteria to ensure that no single fault failure will occur. These mitigations take into consideration the worst-case scenario operational environment(s) and specific policy is in place regarding the positioning reference systems that are allowed. The submarine rescue environment is most closely related to the remote operational environments of the Mobile Offshore Drilling Units (MODUs) and Construction vessels', where choosing the correct reference positioning system(s) is key to a safe and successful evolution. This article compares these military protocols to the Marine Technology Society's (MTS) DP Operations guidance and the ABS DP guidance, offering streamlined recommendations for risk management.

Abbreviations/Definitions

ABS	American Bureau of Shipping
BDS	BeiDou Satellite System
CysScan AS	CyScan Absolute Signature
DGPS	Differential Global Positioning System
DNV	Det Norske Veritas
DP	Dynamic Positioning
DP1	Dynamic Positioning Class 1
DP2	Dynamic Positioning Class 2
DP3	Dynamic Positioning Class 3
DPS	Dynamic Positioning System
GLONASS	Global Navigation Satellite System
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
HiPAP	High Precision Acoustic Positioning System
IACS	International Association of Classing Societies
IAN	Inertial Aided Navigation
IMCA	International Marine Contractors Association
IMO	International Maritime Organization
LBL	Long Baseline
LWMS	Lightweight Mooring System
MODU	Mobile Offshore Drilling Unit
MOSHIP	Mothership
MSC	Marine Safety Committee
MTS	Marine Technology Society
MUV	Manned Underwater Vehicle
NATO	North Atlantic Treaty Organization
NSRS	NATO Submarine Rescue System
PR	Position Reference
PRS	Position Reference System
ROV	Remote Operating Vehicle
SBL	Short Baseline
SRC	Submarine Rescue Chamber
SRS	Submarine Rescue System
SSBL	Super-short Baseline
TTFR	Time To First Rescue
UK	United Kingdom
USBL	Ultrashort Baseline
VOO	Vessel of Opportunity

Introduction

Submarine rescue has been going on since the early 1900s, where the first submarine escape apparatus was derived from the same equipment used by coal miners, a soda-lime cartridge (Stewart). Over the decades the submarine rescue community has evolved to use manned underwater vehicles (MUV) and rely on classed vessels to be able to keep station over a distressed submarine for rescue operations. Today, countries with submarine rescue systems include Australia, Brazil, China, France, India, Italy, Japan, Korea, Russia, Singapore, Spain, Sweden, Turkey, and the United States of America (Rescue Systems). In addition, there is a NATO Submarine Rescue System (NSRS) that is based in Faslane, UK. The NSRS is owned and operated by Norway, France, and the United Kingdom (Rescue Systems).

The last U.S. submarine rescue was in 1939, the FALCON was the vessel used to deploy the Submarine Rescue Chamber (SRC) down to the hatch of the submarine, USS Squalus (SS-192). During this rescue the FALCON maintained her position by laying out four-point moorings in approximately 240 feet of water (40 fathoms). This was not an easy feat due to the rough on-scene weather conditions, over five hours passed between the FALCON commencing mooring and the first diver being put over the side (Commander Rescue Operations). As with all rescue missions, time is of the essence in the submarine rescue community; consequently, a set of rescue plans exist for numerous locations across the globe. Research and planning are conducted ahead of time in areas of concern to include a calculation of an estimated Time to First Rescue (TTFR). The U.S. Navy still maintains and trains with a four-point mooring system, the Lightweight Mooring System (LWMS), however critical and ample time can be saved by taking advantage of the Dynamic Positioning (DP) technology. A DP system can automatically control a vessel's position and heading by utilizing the vessel's thrust components. This automatic computer-controlled system relies on position reference systems (PRS) and weather/environment sensors (i.e., wind, current, speed over ground) to know how much thruster to use where.

This modern-day DP technology is extremely helpful to ensure a fast, safe, and efficient TTFR is achieved. However, there are risks to depending on DP technology that should be understood and considered. These risks can be eased by understanding which position reference systems and sensors are being used, and ensuring appropriate redundancies exist to avoid a complete system failure. International rules and standards have been established to avoid these failures and ensure safety at sea during DP operations. The International Maritime Organization (IMO) has developed a hierarchy of the three main DP class categories are DP1 (single mode failure), DP2 (two independent computer systems), and DP3 (two independent computer systems with a separate back-up system behind a fire-flood barrier). The guidelines for DP systems were approved by the IMO Marine Safety Committee (MSC) in May 1994 and updated in 2017 (IMCA). This paper will review the different types of positioning reference systems, the risks that are inherent to remote operations, and will compare U.S. military protocol to the International Maritime Organization (IMO) requirements, the Marine Technology Society (MTS) guidance, and the American Bureau of Shipping (ABS) DP Operations guidance.

DP Positioning Reference (PR) Systems

Every operational environment is different, so extreme care should be taken when planning and choosing suitable PRS and sensors for a DP operation. The first step to choosing suitable PR systems is understanding the two overarching types of systems: absolute and relative position reference systems. An absolute PR system gives an exact geographical position of the vessel, whereas a relative PR system gives the vessel's position in relation to a non-fixed reference (DNV). Absolute PR systems include Global Navigation Satellite Systems (GNSS), acoustic systems, and taut wire; relative PR systems include laser and radar-based systems (Dynamic Positioning Committee, MTS). An acoustic absolute system should be used as a relative system if attached to a non-fixed asset. In addition, relative system could be used as an absolute system if it is installed on a point that is a fixed geographical position.

The Global Navigation Satellite Systems (GNSS) is the most common absolute PR system and most convenient way to maintain position when out at sea operating in remote destinations without fixed reference available. There are four main global constellations or GNSS where satellites exist and can be used for maritime navigation (U.S. Space Force): (1) United States: Global Positioning System (GPS)/Differential Global Positioning System (DGPS), (2) European Union: Galileo, (3) Russia: Globalnaya Navigazionnaya Sputnikovaya Sistema (GLONASS), and (4) China: BeiDou Navigation Satellite System (BDS).[1] This PRS is authorized for submarine rescue operations.

Acoustic PR systems can be operated in an absolute or relative mode. The DP vessel is installed with a transducer that measures the distance to the transponders in the seabed and correlates data to geographic position. However, since the location of rescue operations is unpredictable, we cannot easily rely on pre-positioned seabed transponders or beacons. Although, once an approximate position is known, an Intervention VOO could depart as soon as able to deploy transponders, preferably three or more transponders would be in the immediate area placed strategically around the sunken submarine. Depending on the depth and environment, an ultrashort baseline (USBL), short baseline (SBL), or long baseline (LBL) acoustic PR may be used. A LBL is ideal for deeper depths and usually includes five transponders on the seabed in a pentagon array, ideally with the rescue vessel above the center of the pentagon and a calibration must be completed. This PRS is authorized for submarine rescue operations.

A taut wire PR system is deck mounted and provides a relative position with respect to wire position and the clump weight on the ocean floor. One of the oldest forms of a PR system, it can be accurate in relatively shallow waters but is negatively impacted by current. Movement of wire activates potentiometers mounted in the gimbal head and produces changes of analogue signals proportional to deviation in inclination. These signals are used to calculate the position offset to the DP system (IMCA). This PRS is currently not authorized for submarine rescue operations.

A laser PR system measures the time the laser to hit a target and return to the detector and operate best in favorable weather conditions. Although laser PR systems have improved with modern technology and can operate in multi-target modes. This accounts for greater variations between vessel and target with auto-tilting mechanisms; ultimately increasing the sea state they can successfully operate in (IMCA). Some common laser PR systems on today's market include CyScan AS, Fanbeam, and SpotTrack. This PRS is currently not authorized for submarine rescue operations. Although should be considered if there is a platform for a reflective target. Reflector targets can be battery operated and may also be installed early on scene with another Intervention VOO.

A radar PR system uses microwave transmissions to measure the bearing and range of a vessel relative to a fixed or moving object. A radar PRS functions well in hard environmental conditions such as fog or heavy rain but does need equipment mounted on both the vessel and asset to work properly (IMCA). A few different manufacturers on today's market include Artemis, RadaScan, and RADius. Current military policy does not specify allowance of this PRS and it is recommended to only be considered if there is an appropriate location to be installed. Much like a laser PR system, the reflective target does not need a power source and can be operated with a long duration battery.

Policy

The primary reference for surveying Vessels of Opportunity (VOOs) to assess their Mother Ship (MOSHIP) capability is the MOSHIP Criteria Manual for U.S. Navy Submarine Rescue. The most current revision of

[1] Other GNSS: (1) Indian Regional Navigation Satellite System (IRNSS)/ Navigation Indian Constellation (NavIC) owned and operated by the Government of India, and (2) Quasi-Zenith Satellite System (QZSS) owned by the Government of Japan and operated by QZS System Service Inc. (QSS).

this reference is Revision "E" (Revision "F" is currently in draft). Some top-level requirements of the VOO include assessing the operational capabilities, especially with regards to the maximum allowable cargo load on deck. There is a 1,025 pounds per square foot uniform deck load requirement for the main working deck that needs to be approximately 40 feet by 98 feet to fit the full U.S. submarine rescue system (MOSHIP Criteria Manual for U.S. Submarine Rescue, Rev E). The average freeboard and ballasting capabilities are also assessed along with electrical and refueling availability on deck. Although no specific berthing requirement is currently set in policy, a copy of the U.S. Coast Guard's Certificate of Inspection is surveyed to better understand accommodations and lifesaving equipment onboard. The MOSHIP will be expected to conduct constant 24-7 operations therefore ample berthing and mess availability is considered to include sick bay capabilities. Other items that are surveyed and annotated in the report are water capacity, fuel capacity, firefighting capabilities, small boat availability, and compressed air connections available on main working deck. However, the very first item listed on the survey checklist is DP (followed by mooring details/capability to deploy LWMS). This is a critical starting point of the survey because if the MOSHIP cannot hold position above the sunken submarine, then rescue operations will not be able to be conducted.

Station-keeping shall be conducted with a four-point moor if the VOO or MOSHIP does not meet the DP requirements. The four-point moor has a large footprint on the VOO, needing an additional 2,717 ft^2 area for all LWMS components (MOSHIP Criteria Manual for U.S. Submarine Rescue, Rev E). In addition, pending the on-scene weather conditions, deployment of the LWMS system has proven to add ample time to the TTFR. Therefore, choosing a capable DP VOO in an array of environments is essential to a streamlined rescue.

Per current military policy, a DP VOO shall have at least an International Maritime Organization (IMO) DP Class 2 system with three positioning reference system and at least one system operating off a different principle. In addition, current procedure does not allow the use of taut wire or laser PRS systems for submarine rescue operations (0A-SRS-OVERVIEW&CL-PM-2-15). If the only VOO available has a taut wire, laser, or a fixed reference point system, appropriate adjudication shall be provided; taut wire shall not interfere with the vehicle operations and laser (or a fixed reference point reference system) must have and will only be usable when in the vicinity of a fixed unit (MOSHIP Criteria Manual for U.S. Submarine Rescue, Rev E).

IMO and ABS guidance take into consideration the number of PRS for a DP2 classed vessel; however, does not take into consideration the type of PRS. This is where current military protocol differs. Below is a table simplifying the minimum requirements needed for each ABS DP classification. In particular, the DPS-2 ABS class, there is a minimum requirement for three PR systems. This aligns with military protocol and includes that one of the PRS is operating off a different principle. DPS-3 ABS class also includes three PR systems, however with the additional requirement that one of the PRS is a different compartment that protects it from fire or flooding. Although DPS-3 classification may be preferred over a DPS-2 classed vessel, it is recommended that a DPS-2 classed vessel remain the minimal requirement for submarine rescue operations.

Subsystem or Component	*Equipment*	*Minimum Requirements for each Classification Notation*				
		DPS-0	**DPS-1**[7]	**DPS-2**[8]	**DPS-3** [5] [9]	*Remarks*
Control System	DP Control: Number of Control Computers	0	1	2	2 + 1 in backup control station	See 5/3.5
	Manual Position Control: Joystick with Auto Heading	Yes	Yes	Yes	Yes	
	Manual Thruster Control	Yes	Yes	Yes	Yes	See 4/9.5
	Position Reference Systems	1	2	3	2 + 1 in backup control station	See 5/11, 10/3.3, 10/5.5, 10/7.3
	Sensors: Wind	1	2	3	2 + 1 in backup control station	
	Sensors: MRU[3]	0	1	3	2 + 1 in backup control station	
	Sensors: Vessel Heading [6]	1	2	3	2 + 1 in backup control station	
	UPS	0	1	2	2 + 1 in separate compartment	See 3/9
Backup Control Station for Backup Unit		N/A	N/A	N/A	Yes	See 5/9.3
Consequence Analyzer		No	No	Yes	Yes	See 5/13
FMEA		No	No	Yes	Yes	See 2/11

Figure 1: ABS DP minimum requirements

To supplement this ABS class policy and regulation, MTS offers DP operational guidance and recommended PRS based on operations in the following figure. Of note, for the acoustic positioning systems the water depth given in the table is for guidance purposes only, yet experience has shown acoustic PRS operating successfully at deeper depths than given in this table (Dynamic Positioning Committee, MTS). Since submarine rescue operations are typically under 700 meters (2,296 feet), recommend use of

	Recommended Absolute Position Reference Systems							Recommended Relative Position References Systems if in close proximity to an offshore structure								Sensors
Application on DP	GPS	DGNSS (DGPS + GLONASS) (See Note 2 below)	SBL (See Note 1 below)	USBL/ SSBL (See Note 1 below)	LBL (See Note 1 below)	Taut Wire (See Note 12 below)	Min Number (See Note 3 below)	Artemis	Laser	Radar	Gangway	DARPS	Min Fixed platform (See Notes 4 5 & 6 below*)	TLP/SPAR/etc < min movement (See Notes 4, 5 & 6 below*)	TLP/SPAR/etc > min movement (See Notes 4, 5 & 6 below*)	Gyros, VRUs and Wind Sensors (See Note 7 below)
Drilling	If in deep open water	Redundant - one dual frequency	<700m	<700m	>700m	<350m	3	Y	Y	Y	N	N	3 mixed abs & rel	3 mixed abs & rel	3 relative only	3
Diving	N	Y	<700m	<700m	>700m	<350m	3	Y	Y	Y	N	N	3 mixed abs & rel	3 mixed abs & rel	3 relative only	3
Pipelay	N	Y	N	N	N	N	3	Y	Y	Y	N	N	3 mixed abs & rel	3 mixed abs & rel	3 relative only	3
Umbilical Lay	N	Y	N	N	N	N	3	Y	Y	Y	N	N	3 mixed abs & rel	3 mixed abs & rel	3 relative only	3
Riser Pull in	N	Y	<700m	<700m	>700m	<350m	3	Y	Y	Y	N	N	3 mixed abs & rel	3 mixed abs & rel	3 relative only	3
Lifting	N	Y	<700m	<700m	>700m	<350m	3	Y	Y	Y	N	N	3 mixed abs & rel	3 mixed abs & rel	3 relative only	3
Accommodation	N	Y	<700m	<700m	>700m	<350m	3	Y	Y	Y	Y	N	3 mixed abs & rel	3 mixed abs & rel	3 relative only	3
Shuttle Offtake	N	Y	N	N	N	N	3	Y	Y	Y	N	Y	3 mixed abs & rel	3 mixed abs & rel	3 relative only	3
ROV Support	N	Y	<700m	<700m	>700m	<350m	2	N	N	N	N	N	*	*	*See Note 8 below	2
Floating Production Unit	N	Y	<700m	<700m	>700m	<350m	3	N	N	N	N	N	NA	NA	NA	3
Well Stim	N unless open	Y	<700m	<700m	>700m	<350m	2	Y	Y	Y	Y	Y	2	*	*	2

Figure 2: MTS Operational guidance on position reference systems and sensors.

SBL and/or USBL/SSBL acoustics.[2] Comparing MTS operational environments listed above to the submarine rescue environment, the two highlighted categories are the most closely related, Diving and ROV Support. Note 2 from Figure 2, states that "Owners/operators should consider the advantages of acoustic positioning systems that have an inertial navigation system input to create an Inertial Aided Navigation (IAN) reference sensor. IAN input can be implemented in one of the redundant DGNSS systems or in one of the acoustic position reference systems […] Introduction of IAN in DGNSS and Acoustic Systems provides additional robustness to position reference systems and the means to overcome the limitations on satellite-based position reference systems brought upon poor satellite geometry." In addition, Note 3 from Figure 2, states that "Satellite based systems that use a combination of signals from DGPS and GLONASS satellites provide enhanced redundancy over systems that only use a single satellite source."

[2] Note 2 of the above table states that 'Satellite based systems that use a combination of signals from DGPS and GLONASS satellites provide enhanced redundancy over systems that use only a single satellite source" (Dynamic Positioning Committee, MTS).

Recommendations

Since, submarine rescue operations can be in hundreds of feet of water or thousands of feet of water, the rescue plans must account for a variety of environments. The coastline may be in sight or no physical references may or may not be available. The rescue team must be ready to respond to a variety of different scenarios to include rescue operations in remote places with limited reference systems available. Recommendations to mitigate risks associated with submarine rescue operations are:

(1) If there are targets available for laser or radar PRS, then allow those PRS to be used.

(2) If there are no targets available for laser or radar PRS, recommend mitigating risk to an acceptable level by requiring two different GNSS to be online and available for use.

(3) If there are no targets available for laser or radar PRS, consider rapid installation of acoustic PR system, such as High Precision Acoustic Positioning System (HiPaP), both Kongsberg and Sonardyne have models that can be installed on a VOO in as little as 24 hours if equipment is onsite.

(4) If acoustic PRS is onboard, recommend Intervention VOO installs appropriate transponders in seabed around disabled submarine prior to arrival of MOSHIP on scene.

(5) If there are no targets available for laser or radar PRS, consider using Intervention VOO(s) as platforms for relative targets to serve as a secondary principle.

(6) If available, consider (and give priority to) acoustic positioning systems that have an inertial navigation system input to create an Inertial Aided Navigation (IAN) reference sensor.

Conclusion

The submarine rescue environment is dynamic, and the rescue team must be ready to operate anywhere in the world. The reliability of station keeping is critical to a successful submarine rescue. As DP technology continues to evolve, policy will also need to be reviewed and appropriately updated to ensure maximum efficiency is achieved. In addition, as new challenges are faced by the operator, clear communication of these issues will enable the continued progress and design of technology improvements, increasing the accuracy and efficiency of operations at sea.

Acknowledgements

This research was supported by the Naval Sea Systems Command and Oceaneering. I would like to thank my colleagues from MTS, in particular, William Westmoreland (Kongsberg Maritime, Inc.) and Ivo Beu (Voith Group) for their encouragement, review, and mentorship. Their comments greatly improved this document. I would also like to show my gratitude to Andrew Tang from Fearnley Offshore Supply for sharing his pearls of wisdom with me during the course of this research.

References

0A-SRS-OVERVIEW&CL-PM-2-15. “Submarine Rescue System Mission Scenarios, Operating Checklists & System Overviews.” *0A Procedures Manual*. U.S. Navy, n.d.

Commander Rescue Operations, U.S.S. SQUALUS. *Report of Rescue Operations SS192/S94/H2-10*. 24 June 2016. <https://www.history.navy.mil/research/histories/ship-histories/danfs/s/squalus-ss-192/squalus-ss-192-sinking-rescure-of-survivors-and-salvage/rescue_ops_report.html >.

DNV. “Dynamic positioning systems - operation guidance.” *Recommended practice DNVGL-RP-E307* . DNV, July 2015.

Dynamic Positioning Committee, MTS. *Marine Techonology Society DP Operations Guidance, Part 2, Appendix 1 - DP MODUS*. April 2021.

IMCA. *Guidance on Position Reference Systems and Sensors for DP Operations International Maritime Contractors Association M 252*. April 2020.

King, A. D. “Inertial Navigation - Fourty Years of Evolution.” *GEC Review, Vol 13, No. 3* 1998: 140 - 148.

“MOSHIP Criteria Manual for U.S. Submarine Rescue, Rev E.” Naval Sea Systems Command, 2019.

Rescue Systems. 2022. <https://ismerlo.org/rescue-systems/ >.

Sagnac, Georges. “The luminiferous aether demonstrated by the effect of the wind relative to the aether in a uniformly rotating interferometer.” *Comptes rendus de l'Academie des Sciences Vol.95* (1913): 708-710.

Stewart, Nick. *Submarine escape and rescue: a brief history*. November 2008. <https://jmvh.org/article/submarine-escape-and-rescue-a-brief-history-2/>.

U.S. Space Force. *Other Global Navigation Satellite Systems (GNSS)*. 19 October 2021. <https://www.gps.gov/systems/gnss/#bds>.