Current methods of subsea production systems survey in the conditions of the Arctic region

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Abstract. The development of deposits in the Arctic region and the Far Eastern shelf of Russia is complicated by the presence of ice conditions. The duration of the ice period can vary from 5 up to 9 months, during which the underwater equipment of the field is inaccessible for inspection and repair. This work discusses the methods of inspection and maintenance of subsea production systems that can be used in the development of Arctic deposits.

1. Introduction
The largest volume of hydrocarbons from Russia's offshore fields is concentrated in the Arctic and Okhotsk shelf. This region is characterized by extreme weather and climatic conditions, the presence of ice, and the distance from the coast to the fields can vary from tens to hundreds of kilometers.

The most suitable option for the development of hydrocarbons under such conditions is the use of a subsea production system (SPS), since it is less dependent on weather conditions and the presence of ice.

Special requirements related to the uniqueness of the area, as well as its remoteness, require attention to increase safety, reliability, and reduce response time and the cost of underwater surveillance and inspection. At the moment, in Russian practice, in the event of a failure of underwater equipment during the ice period, the start of repair work is postponed until the release of the water area from the ice.

Operating companies manage kilometers of subsea pipelines and other assets that require inspection, maintenance, and/or repair to prevent operational and environmental hazards and production losses. Underwater surveillance and inspection, as the key component within an integrity management system, is a proactive approach in identifying areas of improvement or noncompliance. In addition to regulatory requirements, a well-designed subsea inspection plan benefits operator by increasing the confidence in subsea equipment and system reliability [1]. Main underwater surveillance and inspection tasks of SPS facilities and pipelines include:

- Visual inspection (general and close)
- Wall thickness inspection; for example, using Ultrasonic Testing (UT)
- Cathodic Protection measurements (CP)
- Non-destructive testing, such as ultrasonic testing (UT), electromagnetic testing (ET)
- Mapping using side-scan sonars and laser bathymetry
- Leak detection
- Environmental monitoring
- Valve and torque tool operations
- Cleaning and removal of marine life
- Chemical injection
- Maintenance and repair

This paper reviews the main approaches for inspection and maintenance of subsea production system equipment, moreover, the main challenges for application of robotic systems, such as remotely operated vehicles (ROVs) and autonomous underwater vehicles AUVs are considered in the conditions of the Arctic region, more generally in the presence of ice. The main challenges of this region are the following:

- the duration of the ice period is from 5 to 9 months
- the need to use vessels that have an Arctic category that allows them to operate in ice conditions
- high risk of breaking the ROV cable when working in ice, due to the low reliability of existing methods of holding the vessel at the point when exposed to drifting ice fields;
- the remoteness of existing bases for the placement of repair equipment and ship bases.
• the use of divers is limited

2. Monitoring and inspection

In the Oil and Gas industry the required reliability performance of subsea equipment has a significant impact on CAPEX (due to high level of design complexity, reliability and conservatism) and OPEX (due to need of periodic inspection intervention replacement and repair), in particular for remote deep-water areas.

Production performance objectives can be achieved by Operators only defining a proper inspection, maintenance & repair strategy (IMR) to verify the state of subsea asset which usually requires robotic systems such as remotely operated vehicle or autonomous underwater vehicle to carry out integrity assessment [2]. Example of remotely operated vehicle is shown in Figure 1.

![Remotely operated vehicles.](image)

Figure 1. Remotely operated vehicles.

Monitoring and inspection of assets can be divided in several main stages:
1. Monitoring of technological parameters;
2. Surveillance and inspection of SPS using robotic systems;
3. Maintenance and repair;
4. Forming the necessary set off spare parts.

2.1. Monitoring of technological parameters

The first step in integrity assessment is to monitor technological parameters. The SCADA system is used for technological parameters’ monitoring and allows continuous measurement of environmental parameters and technological processes at controlled facilities, registers events, warns about unacceptable deviations of parameters, signals about emergency situations, provides data collection and archiving, and generates reports. Typical technological scheme is represented in Figure 2.

![Typical technological scheme.](image)

It’s important to note that, monitoring of technological parameters does not allow to determine the defect or failure of the equipment, or allows indirectly. To assess the integrity, it is required to make calculations based on deviations from the norm or to make a direct visual inspection of underwater equipment.
2.2. Surveillance and inspection of SPS using robotic systems

Divers and robotic systems such as remotely operated vehicles (ROVs) and autonomous underwater vehicles (AUVs) have been utilized for subsea integrity management including inspection, maintenance, and repair (IMR) for over decades. The use of divers in the Arctic is limited, so it will not be considered further.

Depending on the purpose, robotic systems can be generally characterized as inspection vehicles and intervention vehicles.

- Inspection vehicles are utilized to conduct:
  1. Survey and inspection;
  2. Equipment and process surveillance;
  3. Environmental monitoring activities.

- For its part, intervention vehicles are used for:
  1. Operational activities (e.g., Valve Actuation);
  2. Inspection, Maintenance and Repair (IMR).

The above-described classification is general, at the moment modern underwater vehicles allow to combine several functions. A more detailed classification will be given below.

2.2.1 ROVs. Conventional remotely operated vehicles are tethered with umbilical cable and are distantly controlled by a vehicle operator. It can carry out a variety of tasks including survey, inspection, valve and torque tool operations, manipulator-related activities, and underwater inspection. ROVs are capable of operating in deep water depths, carrying out heavy-duty intervention tasks via hydraulic actuation, and providing real-time situational awareness via high-quality videos. Control and data transmission are carried out through an umbilical cable leading to the supporting vessel. The conventional ROV classification by NORSOK is represented below in Table 1 [3].
| Class | General Definition | Detailed definitions |
|-------|-------------------|----------------------|
| I     | Pure observation  | Pure observation vehicles are physically limited to video observation. Generally, they are small vehicles fitted with video camera, lights and thrusters. They cannot undertake any other task without considerable modification. |
| II    | Observation with payload option | Vehicles capable of carrying additional sensors such as still colour cameras, cathodic protection measurement systems, additional video cameras and sonar systems. Class II vehicles should be capable of operating without loss of original function while carrying at least two additional sensors. |
| III   | Workclass vehicles | Vehicles large enough to carry additional sensors and/or manipulators. Class III vehicles commonly have a multiplexing capability that allows additional sensors and tools to operate without being “hardwired” through the umbilical system. These vehicles are larger and more powerful than Classes I and II. Class III A – Workclass vehicles < 100 Hp Class III B – Workclass vehicles 100 Hp to 150 Hp Class III C – Workclass vehicles > 150 Hp |
| IV    | Seabed-working vehicles | Seabed-working vehicles manoeuvre on the seabed by a wheel or belt traction system, by thruster propellers or water jet power, or by combinations of any of these propulsion methods. Class IV vehicles are typically much larger and heavier than Class III work class vehicles and are configured for special purpose tasks. Such tasks typically include cable and pipeline trenching, excavation, dredging and other remotely operated seabed construction work. |
| V     | Prototype or development vehicles | Vehicles in this class include those being developed and those regarded as prototypes. Special-purpose vehicles that do not fit into one of the other classes are also assigned to Class V. |

The use of ROV in the Arctic region is complicated by the presence of ice. This problem has several roots:

- The need to use vessels that have an Arctic category that allows them to operate in ice conditions;
- high risk of breaking the ROV cable when working in ice, due to the low reliability of existing methods of holding the vessel at the point when exposed to drifting ice fields;
- the remoteness of existing bases for the placement of repair equipment and ship bases.

To solve the above challenges, it needs to use vehicles that work autonomously or placed residential at the bottom of sea.

2.2.2 AUVs. Autonomous underwater vehicles are vehicles that perform underwater tasks without a physical connection to their operator. Rather, AUV’s are programmed or controlled by the operator via “acoustic tether”. AUVs are used for observation, surveillance, persistent monitoring, ocean observation, and inspections of subsea infrastructure. These vehicles can also be equipped with ocean sensors to provide ocean observations and measurements [4].

Autonomous underwater vehicles are able to operate depth rating up to 6,000m, unlike ROVs, the use of which is limited for deep waters. AUVs are mainly used for exploring the seabed or for inspecting pipelines, since their speed is several times higher compared to ROV.
The ability to perform subsea interventions without a support vessel allows to significantly reduce OPEX, risks, and carbon footprint, however. Removing the support vessel, and the tether system, creates two main challenges:

- power the vehicle
- communication

Currently, AUVs are limited in their range and duration by their capacities, after the battery is spent, the system must be recovered by recharging. Most AUVs use onboard stored electric energy for propulsion, powering sensors, and acquiring data [4].

The use of docking stations can extend the duration of missions for underwater vehicles by recharging their batteries at sea. Additionally, docking stations may provide a getaway for communication and updates, as well as storing and transmitting data. Furthermore, a tooling suite can be stored changed out subsea via the docking station, which will allow increase operational flexibility even more [5]. However, the stations are not yet commercially available, their application requires changes in the SPS architecture.

2.2.3 Utilization of robotic systems. As described above, the range of tasks performed by traditional underwater vehicles is very similar and is limited by the lack of commercially available solutions. The intervention of robotic systems, in general, allows you to perform the entire range of underwater operations, including:

Figure 3. Kongsberg HUGIN, Autonomous Underwater Vehicle (AUV).

Figure 4. Concepts of docking stations a) Oceaneering, Docking Station, 2018 [5] b) Model of the docking station (Dhanak and Xiros 2016) [6].
• Inspection tasks
  ▪ General visual inspection, including cathodic measurements and marine growth measurements;
  ▪ Close visual inspection additionally requiring physical cleaning for close visual inspection, CP measurements, and crack detection utilizing nondestructive testing (NDT);
  ▪ Detailed inspection including close visual inspection, crack detection, wall thickness measurements, and flooded member detection;
  ▪ Routine pipeline inspection including tracking and measurement of the depth of cover for buried pipelines,

• Maintenance tasks
  ▪ Module replacement
  ▪ Torque and valve operations
  ▪ Chemical injection
  ▪ Removal of foreign objects

• Repair tasks

Capabilities of current subsea robotic systems and technology availability are presented in Figure 5 shown below [1].

![Figure 5](image_url)

Figure 5. Capabilities of current subsea robotic systems and technology availability [1].

3. Conclusion
Taking into account the specifics of the Arctic region and the Far Eastern shelf of Russia, the main technical difficulties in performing IMR in ice conditions can be attributed to:

• the duration of the ice period is from 5 to 9 months
• the need to use vessels that have an Arctic category that allows them to operate in ice conditions
• high risk of breaking the ROV cable when working in ice, due to the low reliability of existing methods of holding the vessel at the point when exposed to drifting ice fields;
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Considering all the factors, it can be concluded that the use of AUV with a docking station or next-generation resident vehicles is the most promising and suitable method that can be applied in the Arctic region and at SPS. The resident device will reduce the response time and eliminate the time for the mobilization of ships, additionally, undeniably reduce operating costs and risks. Updating the design of underwater equipment and its architecture with the inclusion of a docking station will improve the reliability, availability, and maintainability of a subsea production system. However, the problem remains that at the current state of art there are no commercially available solutions of vehicles and underwater docking stations. One of the examples of vehicles that combines the possibilities of working both in tethered and free-swimming modes is a family of devices named Freedom developed by Oceaneering. It is expected that these devices will be used in operation jointly with an underwater docking station by 2022[5].
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