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Dynamically positioned vessels in the arctic: A comprehensive research and development program for the key technologies

Alain Wassink, SBM GustoMSC

Abstract

Offshore oil and gas operations in the arctic poses large challenges for the design of dynamically positioned vessels intended to perform these operations. In general, extreme temperatures, harsh environmental conditions, severe ice loads, a vulnerable ecological environment, lack of infrastructure and stringent but regionally different regulatory requirements are amongst those challenges. In particular, dynamically positioned vessels will be confronted with a new and complex factor: sea ice. Current dynamic positioning systems and control models do not incorporate the influence and prediction of sea ice on vessel movements and therefore have difficulties in applying thruster compensation. Although significant knowledge is available from various sectors in the offshore industry and the commercial shipping industry there are numerous technology gaps which need to be addressed to be able to enable the use of dynamically positioned offshore units for the arctic. A three year systematic research and development program has been initiated to develop the knowledge and technologies needed and to apply them to typical designs to be offered to the offshore industry for arctic operations. This program is initiated from the complete range of required design input and technology required for designing a dynamically positioned offshore unit rather than focus on individual technology subjects. It aims to integrate all individual technologies to enable design and construction dynamically positioned vessels for arctic operations. This paper presents the outline of the program.

Introduction

Maritime Innovation Program

The Maritime Innovation Program (Maritiem Innovatie Programma, MIP) is a program to support innovation and technology development in the Dutch maritime cluster and is sponsored by the Dutch government. Offshore oil and gas operations in extreme conditions is one of the key strategic areas presented in this program. Research on the Arctic environmental conditions for new developments in the Arctic, as well as installation and maintenance technology for Arctic conditions are mentioned as key priorities within the strategy agenda of this Program in 2009. In this context the project "DP vessels in Arctic conditions" has been accepted, with the aim of perform research and development (R&D) into:

- Research on prediction of sea ice conditions for the Arctic regions and modeling of ice formations, in coherence with meteorological and oceanographic models, and its impact on DP vessels;
- Robust designs of DP vessels that are capable of withstanding the harsh Arctic conditions and provide sufficient protection for the crew on board;
- Development of sustainable solutions to minimize environmental impact of offshore oil and gas activities in the Arctic.

The "DP vessels in Arctic conditions" project, which has been initiated by GustoMSC as lead participant, is a joint R&D project with several companies and knowledge institutes to investigate the special Arctic circumstances and their impact on vessel design and DP systems in particular. In this project, GustoMSC cooperates with an expert on exhaust systems, Discom, in order to minimize environmental impact, and an expert on marine environmental data, BMT Argoss, for providing knowhow on Arctic conditions. The consortium will be supported by other specialists (subcontractors in the project), including Delft University (material science), Aker Arctic (model tests in ice basin) and several specialist companies in the field of exhaust gas treatment.

Motivation

In recent years, offshore oil and gas exploration and field development are increasingly focused on the Arctic waters. The U.S. Geological Survey (USGS) estimated that as much as 25 percent of all recoverable resources (oil, natural gas and natural gas liquids) yet to be discovered are to be found north of the Arctic Circle, see also the figure below.

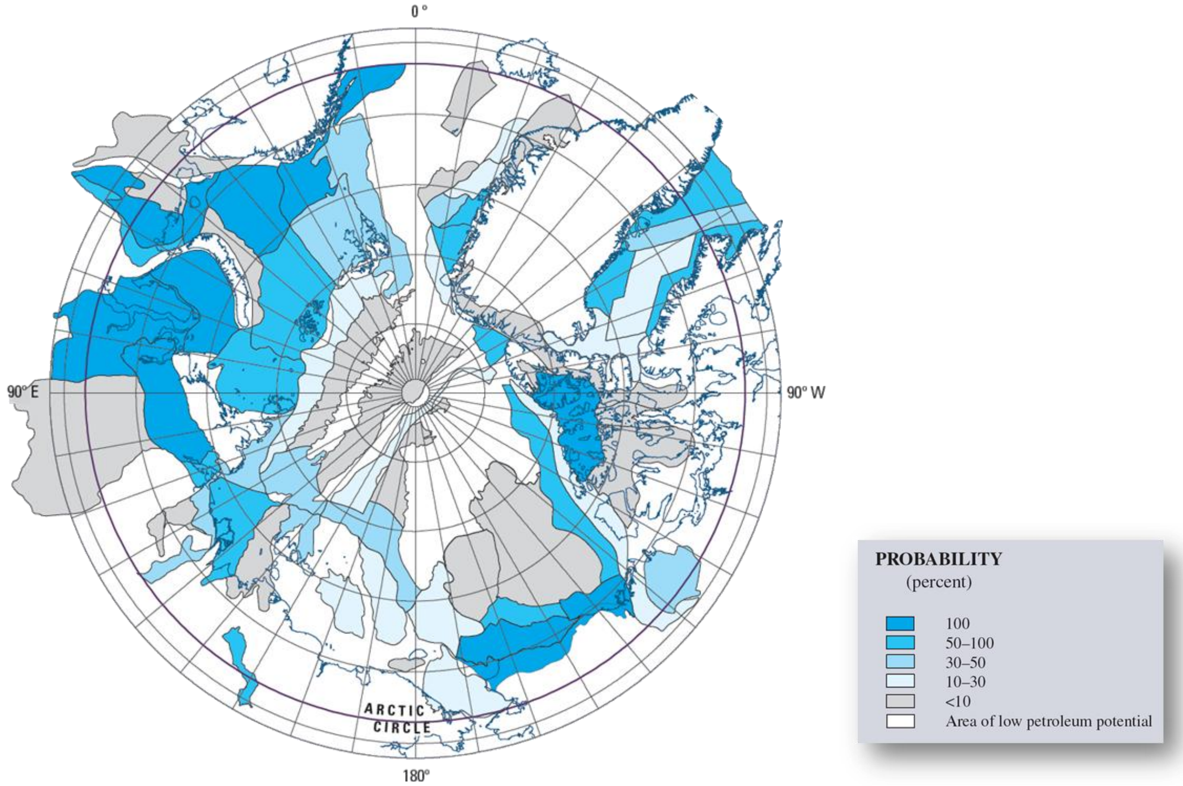

Figure 1 Potential of Arctic oil & gas reserves (source: USGS)

Exploration and production activities in the Arctic region represent many challenges for the offshore industry. The industry has extensive experience and knowledge on designing and operating special vessels and oil and gas structures but yet limited knowledge to design the same vessels for Arctic conditions with extreme low temperatures and ice formation. In addition, the industry is confronted with serious environmental concerns; the society at large has an expectation that such activities will need to be undertaken with “zero environmental footprint”.

The large (proven and undiscovered) recoverable resources in Arctic regions and high oil prices give an impetus to advance the technological development for offshore Arctic regions. In this project, the participants aim at developing solutions to set a basis for development of different types of offshore units equipped for the harsh Arctic conditions. The main focus in this project is specifically on Dynamic Positioned (DP) vessels in ice infested environments, as DP is considered a ‘key tool’ to enable further Arctic developments.

Project objectives and results

The project’s objective is to obtain and develop the knowledge, tools and a generic design framework to make the design of DP vessels that can operate in Arctic conditions technically feasible. This work will build on the available knowledge in the offshore and shipping industries of DP systems and vessels and ice going vessels, and focus on combining these two knowledge bases and developing new knowledge where required. On the one hand this project will result in knowledge and prediction models:

1. Knowledge of metocean and ice conditions and operational conditions
2. Meteorological and oceanographic prediction models of the Arctic
3. DP control model for Arctic environments

On the other hand, the project will also result in some concrete developments:

1. Development of generic hull designs that are fit for extreme low temperatures and ice-impacts
2. Development of DP systems for Arctic conditions
3. Development of exhaust gas emission reduction systems specifically for Arctic conditions

Technological innovation

As has been discussed, extensive knowledge on either the design of DP vessels or ice going vessels exists in the offshore and shipping industries. The technical challenges in this project are therefore primarily related in combining these two knowledge bases and closing the knowledge gaps between the two. The main challenges that have been identified to be addressed in this project are summarized below:

- The relations between environmental loads, such as wind, waves, current, and ice and incorporating these in an complete and reliable prediction model for use in site specific (location) and design specific (vessel design) studies;
- Ice loads and their influence on the DP system (the interactions and required corrections of the DP system). Current DP systems have difficulty in coping with the high loads and the stochastic nature of the loads resulting from ice loads on the vessel. The question is how to incorporate this ‘ice factor’ in a DP control system?
- Ice loads on the vessel and structural response of the hull structure. Local, global and fatigue loads resulting from ice interaction are different in nature than wave action. In addition, the extreme cold temperatures impact the properties of steel and other materials;
- Understanding ice loads and how to influence them. Ice loads are still difficult to assess numerically, but practical vessel design is severely hampered by exclusive reliance on modeltesting. Reduction of ice loads to reduce loads on the DP system and hull structure will be required to make DP operations in the Arctic economically feasible;
- The potential occurrence of ice underneath the vessel and its (potentially damaging) influence on the propellers, thrusters and other equipment underneath the vessel (i.e. drillstring or stinger);
- The influence of the Arctic environment, ice and cold temperatures on particular DP related systems such as hydraulics, flexible joints, position reference systems and sensors, etc.
- Goal for “zero emission” of polluting gases: advancement of current gas removal technologies are needed, and also the small soot particles, up to PM2.5, need to be washed out. The influence of cold temperatures on scrubbing and catalysts performances is not known;
- Providing a safe and healthy working environment on board in a harsh environment (low temperatures, drifting snow, poor visibility, slippery conditions, etc.).

These main challenges are expected to require technology innovation in a number of areas. These areas can be grouped in three main themes:

1. Knowledge of and prediction of ice and metocean conditions;
2. Vessel design knowledge and technology;
3. Environmnetally sustainable solutions.

The main themes are further discussed in the sections below.

Knowledge of and prediction of ice and metocean conditions

A prerequisite for developing designs of DP vessels for Arctic conditions is to have a good understanding of the ice and metocean conditions in the Arctic. Ice and metocean conditions are required to determine environmental design criteria for DP vessels in the Arctic. Fundamental knowledge of the Arctic environment is required to allow the development of prediction models for the Arctic.

With the project partners experience is available with ice data collection and modeling from projects in the Caspian Sea, where during winter ice is enclosing offshore installations; the environmental conditions in the Caspian Sea, however, are different than in the Arctic environment: the climate, ice formation, and water depths are completely different; therefore, new models need to be developed that will give predictions on wind, current, waves and the weather, but also on the drift and direction of ice features such as ridges. In case such features are approaching a DP vessel, the vessel will possibly need to cease its operations. Prediction of ice conditions and features such as ridges in particular and potential influences are therefore very important to assure safe and responsible operation of the DP vessels.

Vessel design knowledge and technology

Within this theme, a number of important subthemes can be distinguished, ranging from DP systems to hull design to working environment.

DP systems

The DP control system consists of a mathematical model that allows the vessel to maintain its position and heading by determining the corrections needed to be made by applying thrust in a given direction. As ice loads are relatively and very stochastic in nature, determination of the required position and heading correction and timely application of the required thrust cause difficulties with today’s available DP control systems. Taking into account ice conditions into the DP control model requires new algorithm development and a redesign of the current DP control software.

The new DP control system is expected to comprise the following elements:

- A mathematical model of the vessel, to compute the forces acting on it due to the environment.
- A mathematical model of the thrusters, to compute the unit's thrust given the power setting from DP control, and to compute the effective force acting on the vessel taking into account thrust degradation effects.
- A DP control module for position feedback. This module uses the data from the environmental prediction models as input. The includes, amongst others, wind feed forward, wave drift forces feed forward, ice forces feed forward and an optimum thrust allocation method.

Next to the DP control system, the overall design and lay-out and the hardware part of the DP system will be researched, with specific emphasis on the thrusters. Thrusters need to physically withstand potentially damaging forces of ice impact. Also, the influence of the Arctic environment, ice and cold temperatures on other DP related systems such as hydraulics; seals andposition reference systems need to be investigated.

Hull and vessel design

Developments on hull design are expected on three different aspects:

- Hull shape: an optimal design is required that reduces ice loads on the hull and DP system in combination with proper open water performance. Another important requirement is good maneuverability. The hullshape(s) as developed coupled with the new DP system will be tested in an ice modeltest basin;
- Hull structural design: understanding of the hull structural response to local and global ice loading. In addition, the influence of ice loading on the fatigue life of the vessel's structures needs to be understood;
- Offshore operations moving into Arctic regions will push the requirements to mechanical properties of structural steel used outside the limits of the readily available commercial grades. Extreme low temperatures (-45/-50˚C) can make metal brittle, causing cracks in the hull, structure and systems of the vessels. Also properties of other materials might change due to the extreme low temperatures. The properties of high strength steel materials in a cold environment will require fundamental research and testing. Also other materials will need to be investigated. Possible solutions will be found in the application of advanced hull materials, special coatings or 'sandwich' constructions, i.e. steel sheets with an elastomeric material in between. This will give more flexibility, a better support and higher insulation values; if only steel would be applied, the material would need a relatively large thickness to provide the same structural support. Additional problem is that steel transfers the cold from outside the vessel to the inside. With an elastomeric material in between, this problem will be mitigated.

Working environment

The extreme low temperature, icing on board, drifting snow and poor visibility cause very difficult working conditions in the Arctic region. In addition, all systems and the vessel itself are exposed to extreme conditions (risks of freezing of systems, collision with ice ridges, snow storms etc.). The extreme conditions will need to be investigated, and a framework of requirements and potential solutions will need to be set up. Increased application of remote control of systems onboard (operators will not need to physically do the work outside) and new applications of robotics, as is already common practice in some other industries is expected. Also practical solutions, such as preheated deck and equipment (potentially using a heat transfer with the engine room or exhaust system) could significantly improve the working environment on board. In addition, the emission reduction systems will provide a healthier working environment.

Environmentally sustainable solutions

Another key development in this project is the treatment of the exhaust gases, including the reduction of emission of NO_x, SO_x, soot particles, etc. Effectively filtering of polluting components in the vessel's exhaust gases will be performed by the application of gas treatment systems in the vessel's exhaust system. These additional systems in the exhaust system might have a negative impact on the engine's performance (changing pressures), which needs to be mitigated. On the other hand, the exhaust gas treatment system will also function will also function as silencer, reducing the sound emissions of the exhaust gases. The following process innovations will be investigated and developed:

- Air inlet: in order to minimize emissions, it is important that complete combustion of the fuel oil takes place (burning of nearly all fuel components). A good inlet of oxygen is a key pre-requisite for complete combustion. In Arctic conditions the air temperature and humidity conditions might cause incomplete combustion; therefore, potentially, the air inlet needs to be preheated (potentially through an efficient heat exchange with engine).
- NO_x removal: Investigation the Selective Catalytic Reduction (SCR) to remove NO_x. This is a relatively new application in the maritime industry. The expected power requirements of DP vessels for the Arctic will be several times larger than for thise vessels wheand the SCR process will take place at much lower temperatures than re this technology has been applied before, and therefore require further investigation.
- Exhaust pipe catalysts: The effect of cold temperatures and potential frost on the exhaust pipe might deteriorate the performance and life-time of the catalysts materials (mainly used for removal of CO and HC), and therefore will need to be investigated.

- SO_x en soot (particles) removal: several solutions will be investigated for the threatment of SO_x and removal of all small particles (including PM10 and PM2.5). Scrubbing, filters and water injection technology could be a solution, but these processes are very temperature critical. Normally, the gases will need to cool down for effective “washing”, but in Arctic conditions this will very likely be more difficult to control. The composition of fuel oil is not always very stable, and therefore the solution will also need to be able to adjust for concentration fluctuations, and perhaps subsequent steps or multiple cycles within the system might be required to completely clean the gases. The washed-out soot particles will need to remain in a closed storage tank, and cannot be brought overboard.
- Reduction of sound emissions. The emission reduction systems already provide a silencing effect on the sound emissions from the exhaust, but in order to provide a good working environment and reduce the impact on the natural environment, the sound will need to be further reduced. A new design of a silencer, specific for the large engines on board and the environmental conditions (low temperatures, air pressures and humidity), will need to be developed.

Project approach

Within the context of the project, R&D is explicitly recognized as a “means to an end”, i.e. R&D is to serve specific objectives. For the subject project the end objective, as described above, is the ability to design and construct mobile offshore units capable of DP operations in the arctic.

In this context, the project is set-up to transfer the available knowledge and tools from various industries (shiiping, offshore) for application to DP vessels for operation in the Arctic, rather than as a project for fundamental R&D activities. However, where no or insufficient knowledge and tools are found to be available fundamental R&D activities will be employed to develop such. To meet the project objectives two distinctive phase can be distinguished:

- The research phase, aimed at mapping the available knowledge and tools, obtaining and understanding the available knowledge and developing the missing knowledge (closing knowledge gaps);
- The development phase, in which the knowledge and tools obtained and developed in the research phase will be applied in a generic vessel design with the aim of consolidating and benchmarking the results of the research phase.

Research phase

The research phase again can be distinguished in four different parts:

- Mapping available knowledge and tools;
- Obtaining and understanding the available knowledge and tools;
- Gap analysis between available and needed knowledge and tools;
- Fundamental research to develop the knowledge and tools not available.

Mapping of the available knowledge consists largely of desktop studies, attendance of industry conferences and contacts with knowledge institutes and industry expert companies. As identified above, R&D programs, both with individual research institustes and companies or in the form of Joint Industry Projects (JIP’s) are underway for various key knowledge areas, the results of which will need to be understood and become available within the project. For that purpose, a number of JIP projects are joined within the context of this R&D effort.

Where knowledge and tools are found to be readily available, access will be sought to this knowledge to directly apply within the project. A thorough understanding of this knowledge and tools will then need to be assured, which will require application thereof both in the research phase and in particular in the development phase of the project.

Upon conclusion of the investigation of available knowledge, a gap analysis will be performed to map the knowledge and tools as available against those that are expected to be required for design and construct. This gap analysis will be input into the fourth component of the research pahse, fundamental research into not available knowledge and tools.

Fundamental research will be executed if and when necessary. Although formally the result of the gap analysis, a number of key areas have readily been identified as described in the section on technology innovation. These key areas are:

- Arctic environmental data (including ice conditions) acquisition;
- Arctic environmental modeling (including ice conditions) for the purpose of making predictions;
- DP control system, including supporting mathematical models;
- Exhaust gas emission reductions for Arctic conditions.

In conclusion, the research phase of the project is set-up such that it will provide the “tools in the toolbox”, where the “tools” are both knowledge and actual design tools such as calculation methods, software tools etc. This toolbox will enable the design and construction of DP vessels in ice infested waters.

Development phase

The development phase will consist of the application of the knowledge acquired in the research phase into vessel design. The goal of this pahse is therefore twofold: 1) the benchmarking of the results of the research phase to actual design activities, and thereby identifying any missing knowledge, and 2) the development of readily available vessel designs and design concepts for application in Arctic development projects.

In that respect, the development phase will serve to integrate the “tools in the toolbox” and ensure that the results of the research are consolidated. To that effect, the development phase comprises the following activities:

- Identification of vessel types and requirements for the Arctic;
- Conceptual design of one or more typical vessels based on identified requirements. This phase will provide insight in consequences to vessel designs in terms of lay-out, main dimensions and powering, both in absolute terms as well as in comparison to conventional designs. It also serves as input to the next phase of basic design;
- Elaboration to basic design (FEED) level of one of the veesel designs, including modeltesting to validate results. The level of detail accomplished in this phase is comparable with Main Scantling Approval by the major Classification societies.

This approach will result in the practical application of all the knowledge and tools developed in the research phase. Also, areas missed in the gap analysis will be identified and can be added to the activities in the research phase of the project. The application in vessel design also serves to ensure that the knowledge is practically usable and readly available for application in design projects.

Integration of the phases

Key part of the program is an integrated and multi-disicplinary approach to the research and development. Although the above research and development phases will to a large extent be phased in time, the application of the knowledge acquired in the research pahse into vessel design in the development phase will initiate additional knowledge requirements, resulting in additional research activities. Research and development activities will also be addressed in connection with eachother, ensuring that the results will be balanced and consistent in approach and assumptions. An overview of activities and their integration is shown in the figure below.

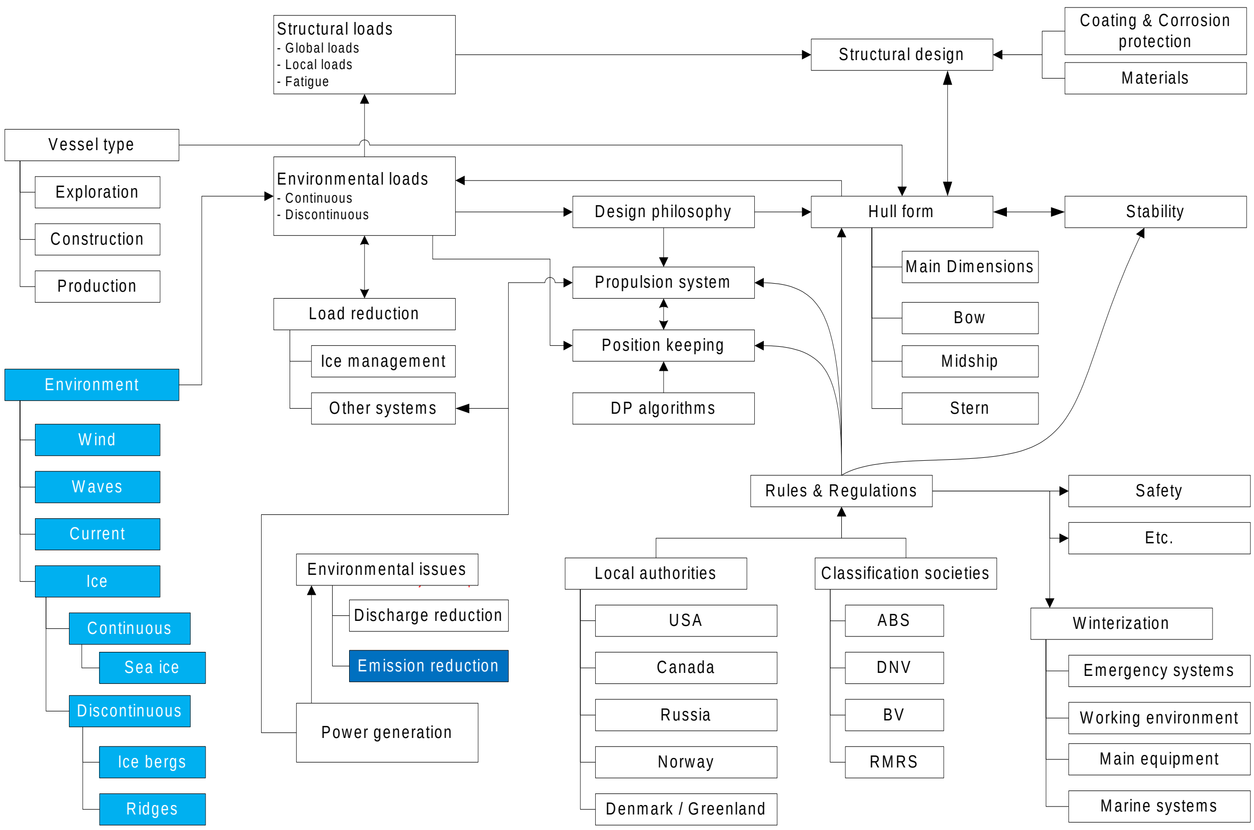

Figure 2 Integrated proram set-up

Conclusions

DP vessels in the Arctic is set-up as a comprehensive program to obtain and develop the knowledge and tools to enable the design of DP vessels for Arctic operations. It builds on the knowledge and tools thus becoming available to apply these in practical DP vessel design, thereby benchmarking them and ensuring they are readily available for use. The program is multi-disciplinary of nature, integrating all disciplines involved to enable operation of DP vessels in the Arctic.

The main advantage of this project set-up is considered to provide a holistic approach to developing vessel designs for Arctic conditions, integrating all key elements thereby ensuring a balanced design. This in contradiction to programs which focus on particular areas of a vessel design, which do not integrate all the variables and compromises typiucally found in vessel design.

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References

[1] MIP project proposal “DP vessels in arctic conditions”, 12-Jun-2009