North Pole ice-resistant self-propelled platform as an innovative complex for research in the Arctic

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Abstract. The Russian presence in the Arctic Region and the development of the Arctic is one of the most important geopolitical interests of Russia. At the beginning of the 21st century, the problem of using innovative methods in Arctic research came to the fore. Based on the analysis of the unique work experience of drifting stations "Severniy Polus" ("North Pole") (1937-2015), Arctic and Antarctic Research Institute specialists have concluded that the stations should be replaced by a modern scientific complex, capable of solving a wider range of problems. As a result, it was proposed to create an ice-resistant self-propelled platform (IRSPP) – an engineering structure for permanent basing of scientific observatories. The IRSPP is designed to conduct year-round comprehensive scientific research in the high latitudes of the Arctic Ocean and should make a long drift of at least one year together with the surrounding ice massive. The scientific complex of the IRSPP includes 16 different laboratories, including an ice load monitoring laboratory. A unique ice load monitoring system (ILMS) has been developed for the IRSPP. The ILMS will be an essential part of the system of safe operation and persistence of the IRSPP and will provide the platform hull with a measurement tool for studying the mechanics of deformation and destruction of sea ice in its interaction with the engineering structures. In all respects, the IRSPP is unparalleled in the world. Its use can open a new chapter in the exploration of the Russian Arctic and in international collaboration aimed at studying the northern latitudes. The platform was put into operation in 2022.

1 Introduction

The Russian presence in the Arctic Region and exploration of the Arctic is one of the most important geopolitical interests of Russia. This is evidenced by the official documents of the session of the Russian Federation Government on "Protecting the interests of the Russian Federation in the high-latitude polar regions", the Security Council of Russian Federation and the Maritime Collegium.

It was decided that the Arctic is Russia's primary strategic resource base. At the same time, the Arctic has an exceptional military and strategic importance for defense purposes. Both the forces of the Northern Fleet and its operational zone, and the largest enterprises of the defense industry complex are based here.

This causes a growing interest in scientific research in the Arctic region. Over many years, the regular studies have been conducted on the Severniy Polus (English North Pole, hereinafter SP) drifting stations, a camp set up on an ice floe. The SP stations were Russian research and operational-production bases, where the nature and mechanisms of formation of hydrometeorological and geophysical processes in the atmosphere, the ice cover and hydrosphere of the central areas of the Arctic Ocean were studied year-round. They collected hydrometeorological information to transmitted it to the World Meteorological Organization, and conducted methodical research. In general, scientific research of drifting SP stations was determined by the programs of Russia's overall research system in the Arctic.

As a result of the research carried out at the stations, a large amount of data was obtained from observations of the state of the Arctic basin environment in the field of oceanography, study of sea ice, atmosphere, ozonosphere, biosphere and ecology.

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2 Life and works at drifting stations

The research data characterize the intensity of processes taking place in the central Arctic and reflect the transformation of its natural environment, which is influenced by the global climate change.

Traditionally, the research programs on the SP stations had to solve the following tasks:

- to carry out a program of standard meteorological, actinometric and aerological observations
- to carry out comprehensive work on background meteorological monitoring of the marine environment
- to study the dynamic-thermodynamic processes and evolution of the sea ice cover
- to identify the thermohaline and hydrochemical structure of water masses in the station drift area
- to evaluate seasonal variability of the components of dolomite system in surface or mixed ocean and the near-surface layer of the atmosphere
- to isolate morphometric parameters of undeformed ice and snow cover and study their changes over time
- to carry out a series of hydrographic studies, including profiling of the sedimentary section in the station's drifting area.

On average, the personnel of the SP stations consisted of 18-20 people, including a medical doctor and technical staff (4-6 people) ensuring the operation of the station. Sometimes, in case of favorable weather conditions and an additional work program, a seasonal team of 6-10 people was brought to the station to carry out construction works and to conduct scientific research under separate programs of the interested academic centers and ministries of the USSR (later the Russian Federation).

After some time, it became impossible to set up the SP stations due to the lack of ice fields, suitable for placing a camp.

Since the 1960s, the AARI (Arctic and Antarctic Research Institute) had been working on the option of using floating structures as long-term drifting bases for scientific observatories instead of the drifting SP stations, as a complex of mobile buildings on a drifting ice field. Finally, the idea of creating an ice-resistant self-propelled platform was presented.

Before starting work on the preliminary project design requirements, a thorough analysis of the organizational and scientific activities of the Soviet-Russian SP stations over time was conducted in order to establish the structural form of the platform. Three major indicators were considered: life safety of the station, cost efficiency and labor.

The financial costs of setting up drifting stations of the traditional type, which included searching for ice fields, relocation of personnel, preparation and transportation of necessary equipment, funding scientific and technical programs of the station, evacuation costs (including in emergency cases), etc. were analyzed. The results of the economic analysis were compared with the costs of construction and exploitation of different variants of an ice-resistant platform, to accommodate a new-type drifting observatory. This allowed to determine the preliminary dimensions of the platform, its displacement and the required usable area inside it.

Analysis of the working process at the drifting station showed that the most labor-intensive operations are: loading of the logistical equipment, building structures and materials, machinery, fuel, and lubricants, food and construction of service and accommodation quarters when establishing a new station on the drifting ice field. In addition, we can mention cases of emergency work, as they can occur at any moment of drifting.

For example, here is a calculation of the labor of the staff of the SP-36 station:

- 100 % of the personnel take part in the arrangement of the camp and its life support.
- 20 to 40 % of personal and working hours of the scientific personnel of the station is spent on station life support and emergency works.

Emergency station rescue operations are conducted due to the fact that the ice fields, on which the stations are based, are constantly under compression, so pressure ridges suddenly form in unexpected places, which can crush houses and equipment, cracks can appear, and the station's size can be reduced.

The labor intensity of work to ensure proper living and working conditions on the drifting ice floes increased due to the fact that it was necessary to organize reserve storage facilities, and first of all reserve stores of oils and lubricants and foodstuffs to ensure safety of material supplies.

It should be noted that due to selfless work of polar explorers and optimal organization of all work, distraction of scientific staff of the stations do the indicated work did not affect the quality and completeness of work under the research programs. However, it can be argued that the specified working conditions of the polar explorers exacerbated the physical and psychological strain on their bodies.

I.D. Papanin sent a telegram on February, 2 1938 during the last working period of the first Soviet SP station: "In the station area, fragments of ice fields not bigger than 70 m in size continue to collapse. Cracks of 1 to 5 m in size, droughts up to 50 m. Ice blocks are mutually shifting. Up to the horizon, the ice is 9 out of 10 tenth. It is impossible to land an aircraft within line of sight. We live in a silk tent on an ice block 50 m by 30 m. A second antenna mast is placed on another ice floe during communications. We have a three-month food supply, equipment and the result. Regards to all. Papanin."

A.N. Chilingarov, the head of the SP-19 drifting station, which unlike Papanin's station was set up on an ice island, wrote: "About twenty meters away from the cabin, parallel to our "main street" there is a wide crack. It passes very close to the food storage, cutting us off from the fuel supplies, gas and the tent with the household equipment. The food storage facility is under the biggest danger. It is a miracle that this whole pile of bags and boxes remained on the edge and did not fall down into the abyss."

Figures 1-4 illustrate the working and living conditions at drifting stations, with the example of the SP-35 station.

Fig. 1. An ice crack at the SP-35 station (Photo by V. Kustov)

Fig. 2. The SP-35 station: access to a residential building during ice and snow melting (Photo by V. Kustov)

Besides, it is important to mention the obvious danger of polar bears visits to the station. Such visits endanger life and health of polar explorers, as well as equipment and food supplies. In particular, dozens of cases of polar bears' presence next to the station and even in the camp were recorded during the drifting period of the SP-35 station (Fig. 3).

Fig. 3. A polar bear in the camp of the SP-35 drifting station (Photo by V. Kustov)

Fig. 4. Demobilization of the drifting station (Photo from the internet)

To summarize, it can be added that living conditions on the drifting ice field limit the possibilities of using modern scientific equipment, expand the duration of explication of research results and reduce their quality, and living conditions are unattractive for young specialists. The last two arguments reduce the effectiveness of scientific research in the balance of costs for creation and maintaining SP drifting stations.

3 IRSPP design

Having analyzed the work of SP stations, according to AARI specialists, the most optimal form is a floating engineering structure to base a research observatory, which has maximum efficiency at minimum construction and operating costs.

In 2015-2016, Vympel Design Bureau and Admiralty Shipyards started to work on the image of an advanced research platform vessel for a research station.

In April 2018, Roshydromet (Russian Federal Service for Hydrometeorology and Environmental Monitoring) and Admiralty Shipyards signed a contract for the design and construction of the ice-resistant self-propelled platform (IRSPP) "Severniy Polus". Construction work started in December 2018 and was put into operation in 2022. The IRSPP is a self-propelled displacement steel vessel (Fig. 5).

The IRSPP is designed to conduct year-round comprehensive scientific research in the high latitudes of the Arctic Ocean and must perform a long drift of at least one-year, together with the surrounding ice massif.

Generally, the platform has Arc5 ice class – autonomous navigation in the first-year ice up to one meter thick. At the same time, the hull strength along the boards and the bottom corresponds to the Arc8 class, which allows coping with the compression of multi-year ice.

The IRSPP has the following main dimensions: length overall/DWL – 83.1/76.7 m, width overall/DWL waterline – 22.5/21.8 m, side height at midship – 11.4 m, draft DWL/minimum – 8.6/7.5 m. The maximum displacement of the IRSPP is approximately 10,400 t. With main engine power of 4200 kW, the navigation speed in deep calm water is at least 10 knots.

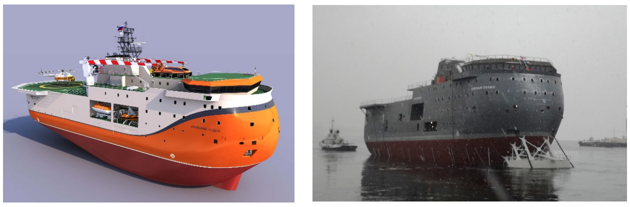

Fig. 5. General view of the IRSPP: 3D-model (left) and the launched (right) (Photos by AARI)

The platform propulsion complex consists of azimuthal thrusters and an azimuthal water-jet propulsor in the bow that functions as a bow thruster. If needed, the IRSPP can autonomously move to a new initial drifting point in open water or in relatively light ice conditions.

Prior to construction of the IRSPP, the AARI conducted a wide range of ice and nautical trials with the platform model in the AARI ice tank [1]. Apart from traditional trials to assess the ice resistance of the moving of the platform, additional experiments were held to observe the effect of ice compression on the IRSPP hull (Fig. 6). Based on the results of the model tests, it was possible to select the optimal hull shape for its successful exploitation in ice conditions.

Fig. 6. Testing of the IRSPP model in the ice tank of the AARI during ice compression. (Photos by AARI)

The standard scenario for a self-propelled platform is as following: the vessel will have to move autonomously or with the help of an icebreaker to a certain point and go adrift. It would be able to freeze into the ice without damaging its own construction and float on with it. Such drifting can last up to two years. If necessary, the vessel can receive or send helicopters with cargo or passengers.

The IRSPP will start drifting in the eastern sector of the Arctic, as well as the SP stations. The best months for the IRSPP to move to the starting point of the drift are August-September, because at this time the extent of the concentrated ice area is minimal.

It is assumed that the personnel on the platform will work on a rotation basis. The platform will comfortably accommodate 54 people: 34 researchers, 14 crewmembers and 6 members of the helicopter team. The IRSPP is equipped with a helipad to receive Mi-38 helicopters. Safe and comfortable living and working conditions are ensured at temperatures down to –50 °C.

The IRSPP is a scientific complex designed to conduct various types of research and observation. It includes 16 different laboratories, including the laboratory of ice load monitoring, which is part of the ice-research complex [2]: meteorological laboratory, atmosphere laboratory, aerological laboratory, satellite hydro meteorological data reception laboratory, geophysical laboratory, ice load monitoring laboratory, sample preparation laboratory, geological laboratory, hydro chemical laboratory, environmental laboratory, oceanographic “dry” laboratory, oceanographic “wet” laboratory, ice research laboratory, ice-research (cold) laboratory, and a laboratory of special research.

Along with the traditional research complex, the creation of a self-propelled platform will broaden the spectrum of research and observation in this area [3]:

- ionospheric observations – based on the receiving station for inclined ionospheric sounding (modern digital ionosounde of new generation with linear frequency modulation) for operative diagnostics of HF radio wave propagation conditions
- geological research – to conduct a wide range of geological studies of bottom sediments in remote and hard-to-reach areas of the Arctic basin, based on a sample preparation complex for using piston ground pipelines and dredges, wet and analytical laboratories, core storage facilities
- chemical and environmental research based on the analytical complex
- acoustic tomography of the Arctic basin - monitoring of hydro physical fields of the Arctic Ocean
- studies of the boundary layer and free atmosphere in the central Arctic
- magnetic and gravitational research – monitoring, in order to determine magnetic and gravitational fields (maps) in high latitudes of the Arctic
- study of ice load and ice mechanics–previously never conducted research on the mechanics of deformation and failure of the sea ice, designed to improve methods for calculating local and global ice loads on vessels and other engineer structures.

4 Ice-load monitoring system (ILMS)

The ice-load monitoring system with which the IRSPP is equipped deserves particular attention. Currently, to ensure safe exploitation, almost all engineering structures and vessels, designed to work in ice conditions, are equipped with ice load monitoring systems (ILMSs). Generally, the main purpose of an ILMS is continuous monitoring of the stress-strain state of an object, when it is exposed to ice loads on it. If the value of measured parameters exceeds the set threshold values, the system generates a warning, based on which the system operator can take measures to reduce the load [4].

The IRSPP is an unconventional engineering structure with its own operating features, so a unique system of ice load monitoring was developed. The ILMS for the IRSPP is designed for scientific purposes, but it also ensures safe working of the platform in ice conditions [5].

The functions and configuration of the ILMS instrumentation were defined based on the operating condition of the IRSPP, analysis of ice conditions and scenarios of ice loading on the vessel's hull, and the results of model tests in the ice tank of the AARI. They were also determined during the Transarctic-2019 expeditions on the scientific diesel-electric research vessel "Akademik Tryoshnikov", where the technology for monitoring ice loads in drift conditions was tested [6].

The main measuring subsystem of the ILMS is the hull stress-strain monitoring subsystem, which is required to measure the response of the hull structure to the effects of the ice-loads in different regimes of platform operation.

Measurements are performed using an extensive system of fiber-optic deformation sensors, placed on the elements of the hull structure. Taking into consideration that the most interesting processes are interactions of the hull and the ice during ice compression, the majority of the sensors are placed in the central part of the hull [5].

The main feature of ILMSs for the IRSPP is that it includes a subsystem for estimation of the parameters of the stress-strain state of the ice adjacent to the IRSPP. This subsystem will be connected to the ILMS only during the drift of the IRSPP. At the first stage of IRSPP operation as a part of this subsystem, the measuring elements in this subsystem will be membrane type pressure sensors, which will be frozen into the ice cover in two mutually perpendicular destinations at different horizons along the ice thickness. The subsystem is necessary to study the processes of interaction between the ice field and the hull of the IRSPP, it will allow tracing the balance between the ice cover and the pressure which the ice exerts on the platform board. Also, measurements of the surrounding ice sheet (primarily thickness and physical and mechanical characteristics of the ice) will be made during the drift, which will help to supplement the data obtained by the ILMS.

Apart from that, the ILMS allows to collect data on kinematic parameters of the IRSPP motion (angle of heel, trim, yaw angle, linear-acceleration in three axes); meteorological data (air temperature, wind speed and direction); parameter of the propulsion complex (power, RPM, steering angle of the azimuth thruster); coordinates, speed and course of the IRSPP.

It should be noted that the currently existing implemented projects of ILMSs are not intended for measurements in ice compression conditions. Thus, the mentioned ILMS makes the IRSPP a unique scientific measuring complex for studying the processes of ice impact on structures obtaining new data on the parameters and ways of the ice-load action.

5 Conclusion

In all respects, the IRSPP is unparalleled in the world. Its construction may open a new chapter in the research of the Russian Arctic and in international collaboration aimed at studying the northern latitudes. A self-propelled platform as a base for a research station has its obvious advantages compared to an ice field. It is safe, predictable and manageable, it is possible to conveniently and effectively place there a big amount of research equipment, provide its power supply and operability Finally, it is easier to create comfortable working conditions for crew and scientists. Such a floating observatory will make it possible to monitor most of the Arctic basin and promptly obtain reliable scientific data on natural processes in the northern polar regions of the Earth.

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