Cryogenic pumps of mobile machinery

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Abstract. Cryogenic pumps are of particular importance in mobile machinery, in particular in wheeled and tracked vehicles. This is due to the development of hydrogen energy. In the nearest future, we will see hydrogen powered mobile cars. In this regard, it would be useful to have an up-to-date overview of modern cryogenic pumps. This article discusses the main types of cryogenic pumps, identifies problems encountered in the design and operation of pumping units and formulates the requirements for these devices. A brief overview of the most common designs of cryogenic pumps of foreign and Russian production is presented.

1. Introduction
In the modern world, cryogenic products are an integral part of many technological processes in the energy sector, oil and gas industry, metallurgy, astronautics, chemical industry, medicine and many other areas of human life [1]. Cryogenic products include substances or mixtures of substances at cryogenic temperatures (below 120 °K). The most common cryogenic products are low-temperature air separation products and inert gases: nitrogen, oxygen, argon, neon, krypton, xenon, ozone, fluorine, methane, hydrogen, helium. To produce, store, transport and use cryogenic products, special devices are required that correspond to the special properties of liquefied gases and ensure the safety of personnel when working with cryogenic products. [2]

2. Overview of the types and designs of cryogenic pumps
Cryogenic pumps are designed for pumping cryogenic products and can be of piston or centrifugal type. Reciprocating cryogenic pumps are used to produce and transport liquefied gases such as oxygen, nitrogen, hydrogen, helium, argon, natural gas. Using pumps of this type, cryogenic liquids are pumped into tanks and cylinders, and piston pumps are included in gasification plants. These pumps are used for small volumes of pumped product in the medium and high pressure range. [3]

Another type of cryogenic pumps is centrifugal pump. There is huge modeling experience on centrifugal pumps [4]–[7]. Of particular interest are publications [8]–[13]. Cryogenic centrifugal pumps are used in air separation plants both for compressing a cryogenic product and for circulating a coolant in the system. In addition, with the help of centrifugal pumps, liquefied gases are pumped from tankers and storage facilities and the cryogenic products are subsequently delivered from tanks to the consumer (for example, filling gas vehicles). Centrifugal pumps can have a single-stage or multistage design. In multistage pumps, the pumped liquid passes sequentially through several impellers, between which guide vanes are located for supplying fluid from the previous stage to the next. This design allows to significantly increase the pump head in comparison with a single-stage pump. [14]
When creating cryogenic pumps, difficulties arise due to the properties of cryogenic products, and in particular their low temperature. Therefore, due to the low temperature of the pumped liquefied gas, a large temperature difference is created between the wet part of the pump and the ambient medium. Because of this, water condenses on the outer surfaces of the pump and forms a layer of frost. Heating of the cryogenic product due to external heat gain and heat generation during operation can cause cavitation, because all liquefied gases are low-boiling. To keep coolant in a liquid state, it is necessary to maintain a low temperature and high overpressure. Incorrect design of the wet part of the cryogenic pump can lead to cavitation and, as a result, to cavitation erosion and loss of pressure. Therefore, hydrodynamic modeling of flows in the wet part of the pump is a very useful design tool, as it allows one to determine the optimal pump parameters. [15] In addition, the calculation of the pump cavitation characteristics is complicated due to the presence of two phases in the flow (liquid and vapor). To solve problems in this formulation, various methods can be used, for example, those given in [16] and [17]. For cryogenic pumps, when finding a critical suction head, it is necessary to take into account corrections related to the influence of gas inclusions, the viscosity of the pumped medium, as well as its thermophysical properties. The seals in the cryogenic pump operate in conditions of insufficient lubrication, since cryogenic products seeping through the gap between the wear surfaces quickly evaporate at ambient temperature. In addition, the seal freezes, and hoarfrost falling into the friction zone leads to increased wear of the parts. Bearing units of pumps can fail much earlier than the expected resource, since the lubricant in them freezes and ceases to fulfill its functions. In addition, the low temperature of cryogenic products can lead to embrittlement of pump parts. In addition, some liquefied gases are toxic, flammable or explosive, so the sealing units must provide either complete sealing or minimal controlled leakage. [18]

Thus, a number of requirements for cryogenic pumps can be formulated.

1. Reduce heat influx to the pumped product to minimum values. To do this, it is necessary to insulate the pump casing.
2. Ensure reliable operation of seals and friction units without the use of lubricant.
3. Ensure reliable operation of bearings throughout the entire life. To do this, one can separate the flow part and the shaft bearings to reduce heat transfer between them or use bearings lubricated directly by the pumped liquid.
4. When choosing materials for pump parts, it is necessary to take into account the temperature and chemical activity of the pumped cryogenic product. The suitability of the material for operation at a given temperature is judged by the temperature viscosity margin equal to the difference between the operating temperature and the cold-shortness threshold.
5. When working on combustible, poisonous, or rare gas pumps, product leakage must be avoided.

One of the common types of pumps used for pumping cryogenic liquids is a close-coupled electric pump (electric motor and cryogenic pump combined in one unit). This type includes the pump NkpM. It is used for discharging and filling tanks in storage and transportation systems for liquid cryogenic media, as well as in air separation metallurgical plants. Pumps NkpM are of horizontal and vertical execution, one- or two-stage. Capacity range of these pumps is from 3 to 200 m³/h and pump head range is from 25 to 90 m. Fig. 1 shows a section of a vertical close coupled centrifugal pump of NkpM type with a housing for insulating fill.

It is also worth paying attention to cryogenic centrifugal pumps from Cryostar (France). They are designed for pumping liquefied gases (nitrogen, argon, oxygen, methane, hydrogen, carbon dioxide, etc.) from one cryogenic or isothermal tank to other under pressure from 2 to 100 bar, as well as in various low-temperature technological processes. Pumps have a wide range of capacities — from 10 to 10,000 l/min. One of the most common is the GBS pump (Fig. 2) [19].

The advantages of this pump include the increased resource of the composite seal (compared with graphite), good protection against heat influx and the possibility of easy seal change due to the removable housing cover.
Fig. 1. Vertical close coupled centrifugal pump NkpM type with a housing for insulating fill: 1 — electric motor; 2 — motor stool; 3 — spacer ring; 4 — key; 5 — spacer washer; 6 — extension shaft; 7 — fitting; 8 — cover; 9 — pin; 10 — key; 11 — sealing ring; 12 — sealing ring; 13 — pipe; 14 — expandable ring; 15 — screw; 16 — cap flange; 17 — nut; 18 — stub; 19 — bushing; 20 — impeller; 21 — spring; 22 — housing; 23 — cap flange; 24 — stub; 25 — guide vanes; 26 — support ring.
Fig. 2. Cryostar GBS pump: 1 — removable housing cover; 2 — composite mechanical seal; 3 — impeller; 4 — screw inductor; 5 — gear box; 6 — gear; 7 — bearings; 8 — hollow spokes connecting the pump to the electric motor; 9 — shaft; 10 — plate with low thermal conductivity.

Fig. 3. Flowserve WUC submersible pump.

Fig. 4. Electric pump 4HGV-6-40-5: 1 — motor cover; 2 — thrust bearing; 3 — upper bearing; 4 — stator; 5 — rotor; 6 — lower bearing; 7 — hydraulic balancing device; 8 — guide vanes; 9 — impeller; 10 — pump housing; 11 — support.
Submersible centrifugal cryogenic pumps provide the most effective thermal insulation, as they are located directly in the pumped medium. This type includes the WUC pump (VS6) from Flowserve (USA) (Fig. 3) [20]. The temperature of the pumped liquid is from -200 °C to 350 °C. Pump head up to 2000 m, pressure up to 200 bar. The seal chamber is standardized and allows the installation of dual liquid, dry gas or gas injector labyrinth seals.

It is worth noting there are leak-free pumps for cryogenic liquids. In these units, external heat inflows are not eliminated as efficiently as in submersible pumps, but cryogenic product leaks are excluded. Electric pumps of the HGV series (Russia) are intended for pumping aggressive liquids containing harmful substances, including liquefied gases, at temperatures from -50 °C to 100 °C. Fig. 4 shows a 4HGV-6-40-5 pump.

3. Conclusion

Thus, we can say that the efficiency of the cryogenic pump largely depends on the design, or how the characteristic problems of cryogenic pumps were solved related to the special properties of the medium. The most rational solution to these problems determines the promising directions for the development of cryogenic pumps, which include the following:

1. The use of new materials resistant to low temperatures in the design of pumps.
2. The implementation of effective thermal insulation of pumps (for example, using powders, fibers, organic foams) [1].
3. The use of leak-free pump arrangements in order to avoid problems with seals.

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