SVANEHØJ CS FUEL PUMP SOLVES CHALLENGES RELATED TO SUBMERGED LNG PUMPS

With the design of the CS Fuel Pump – an electric submerged fuel pump for LNG-powered ships – Svanehøj has introduced two significant innovations: 1) A self-cleaning LNG filter combined with an internal secondary flow that solves the problem of clogging and 2) a novel permanent magnet motor designed for marine purposes to save energy and avoid boil-off gas caused by heat generation.

Liquified natural gas (LNG) has been a marine fuel option for decades. However, LNG has not made its mark in the commercial marine fuel market until recent years. Since 2010 the number of LNG-powered ships has grown consistently by 20-40% annually. By the end of 2022, almost 900 LNG-powered vessels were in operation or on order, and further growth is expected in the coming years. Two different fuel pump technologies are used for LNG-powered ships: Submerged and deepwell pumps. Both pump types are driven by electric motors, respectively, placed in the tank and on top of the tank. The deepwell pump has considerable technical advantages. But due to the long shaft and the motor base arrangement, it is also, in some configurations, more expensive, which is why the submerged pump is the dominant standard in most segments.

As LNG has become more widely used as a marine fuel, ship operators have experienced challenges regarding the submerged pumps. To prolong service intervals and avoid short circuits, the liquid that cools the motor and lubricates the bearing must be filtered. Several pump manufacturers use external or internal filtration solutions (or a combination) to filter all the LNG flowing through the pump. But the filters tend to get clogged by impurities in the liquified gas, resulting in unavailable pumps and excessive wear on bearings and motor components. ▶

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Powering a better future

Another issue is the electric submerged induction motor, which is a common design standard in the industry. Several scientific studies have shown that this motor type struggles with low efficiency, small torque density, and extensive heat generation. Extensive heat generation in the motor housing is undesirable as the LNG may evaporate and become gaseous (boil-off), resulting in poor bearing lubrication and loss of motor cooling, ultimately degrading performance.

New pump design to solve LNG challenges

In 2021, Svanehøj set out to solve the challenges regarding the submerged cryogenic pump for LNG-powered vessels by designing a new solution, the CS Fuel Pump, initially launched in the fall of 2022. The challenge regarding clogging has been solved by the design of a self-cleaning LNG filter, while a new Interior Permanent Magnet motor has been designed to offer a high-efficiency motor that reduces the amount of boil-off gas.

Self-cleaning LNG filter

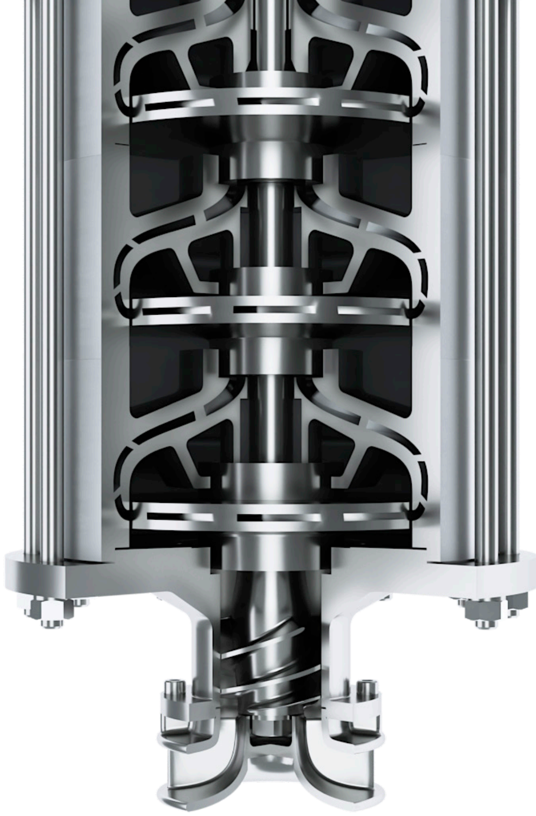
Cryogenic submerged pumps are traditionally designed with a filter through which all the LNG flows. This solution has proven ineffective because of clogging. The Svanehøj CS Fuel Pump is designed with a ‘strainer’ with 3 mm holes on the suction side of the pump to catch loose debris, while only a tiny fraction of the main LNG flow passes through the pump’s self-cleaning LNG filter (4-6 l/min, which is necessary for cooling and lubrication).

The self-cleaning LNG filter for the CS Fuel Pump is a side flow filter element developed by Svanehøj in close cooperation with industry specialists. The filter is placed in the discharge pipe, through which the secondary flow is filtered for improved motor cooling and lubrication of the motor bearings (see Figure 1). The unit is designed without moving parts to make it easier accessible for service or interchange once the fuel tank is emptied of LNG.

A specialized test stand has been constructed to verify the filter system’s functionality and for further development of the LNG filter element. The tests are carried out in water infused with contaminant particles of controlled size and count.

High-efficient Interior Permanent Magnet (IPM) motor

An essential aspect of the CS Fuel Pump is the Interior Permanent Magnet (IPM) e-motor which is designed to run fully submerged in the pumped cryogenic fluid.



In cryogenic conditions, the motor performs with an efficiency of 96.8% compared to the industry standard of 84-88%. Because of the higher efficiency, significantly more electrical energy is converted into mechanical power, thereby saving energy, and avoiding boil-off gas caused by heat generation.

The Svanehøj IPM e-motor is developed in collaboration with recognized motor suppliers with more than 80 years of experience in the industry. The design is substantiated and based on extensive research, development, and testing. ▶

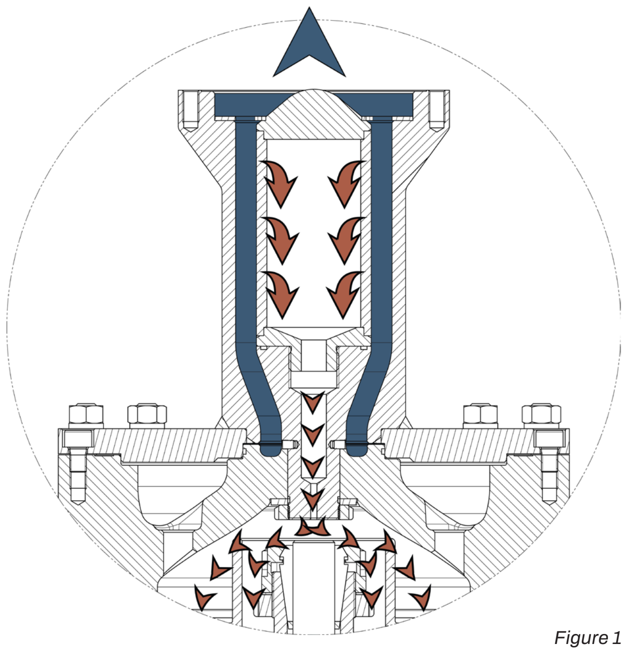


Figure 1

Why choose an IPM e-motor?

The choice of the IPM e-motor design is based on four main arguments: 1) Efficiency, 2) Weight and dimensions, 3) Gap between the stator and rotor, and 4) Future prospects.

1) An induction motor uses significant energy to form a magnetic field in the rotor. An IPM motor does not require energy to form a magnetic field, as it is incorporated by the permanent magnets. The IPM motor design is stable at low temperatures, with low coercivity, loss of cooling, and remanence temperature coefficient. A study of a 20-kW induction motor from a leading supplier in the industry showed an efficiency of 87%, meaning that 13% of the supplied energy converts into heat, thereby increasing the risk of boil-off gas, dry running of bearings, and significant damage. Preliminary testing of the Svanehøj IPM e-motor shows that just 3% of the supplied energy converts into heat, significantly reducing boil-off gas and the risk of damage.

2) The 20 kW IPM e-motor from Svanehøj weighs 20 kg, nearly half of the 20-kW induction motor from the leading supplier mentioned above. At the same time, the stator diameter in the IPM e-motor is 148 mm. compared to 200 mm. in the induction motor. The lower weight and smaller size reduce the use of materials.

3) With a gap of only 0.5 mm. between the stator and rotor, the induction motor requires ball bearings on both sides of the rotor. The Svanehøj IPM e-motor is designed with a 1.5 mm gap between the stator and rotor, which only necessitates one hybrid ceramic ball bearing. The larger gap improves the stability of the pump.

4) The IPM motor is the solution for future LNG pumps, as there are inherent drawbacks related to the induction motor design. A Permanent Magnet Motor design is smaller, more efficient, and more reliable at low temperatures.

How the IPM e-motor is built

The Svanehøj IPM e-motor is built with full-face bonded rotor and stator laminates for the most stable, rigid, and strong lamination pack. The permanent magnets are retained in slots by small springs cut into rotor laminates (see Figure 2). The pump is built with only one media-lubricated ceramic ball bearing for taking up axial forces.

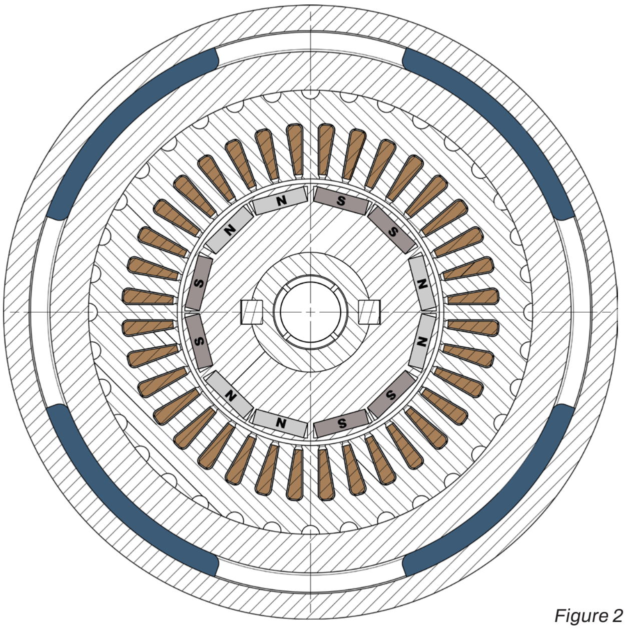


Figure 2

All other bearings are of the well-proven and robust radial carbon bearing design. The motor stator is fully potted with a special heat-conductive resin, rated for cryogenic operation, to prevent problems with short-circuiting due to tiny electrically conductive particles accumulating in the copper windings over time. The potting fully encapsulates the copper windings preventing any containments or moisture from entering the stator.

The IPM e-motor is designed to run fully submerged in the pumped cryogenic fluid. Two prototypes were built and tested in liquid nitrogen (-196°C). The tests confirmed that the IPM e-motor performs well at low temperatures, and the hybrid ceramic bearing withstands very harsh conditions.

Svanehøj IPM e-motor details

Rated power: 20 kW (@4560 rpm)
Efficiency: 96.8% (@-162°C)
Poles: 6 (12 magnets in pairs)
Core dimensions: Ø 148 mm x 180 mm
Core weight: 20 kg
Topology: V-IPM

Cryogenic conditions require specialized pumps

Keeping LNG in its liquid form requires cryogenic conditions of at least -162°C (or with the relative pressure built up). LNG pumps must therefore be highly reliable, durable, and constructed from materials that function optimally under cryogenic conditions.

The CS pump is designed with:

- long stay-bolts for maximum elasticity and handling of the variance in thermal expansion between materials under cryogenic temperature.
- a cryogenic collet connection for interlocking the motor- and centerless ground pump shaft.
- one hybrid ceramic bearing for taking up all axial forces.
- carbon journal bearings for radial loads.
- a secondary flow driven by pressure differential over the last pump stage. This principle is verified by computational fluid dynamics (CFD).
- fully closed and cast intermediate chambers, which provide reduced hydraulic loss and lower production costs.
- a double-wear ring with a labyrinth seal design for better hydraulic performance and reduced leakage.
- impellers with splitter blades to increase the pressure per stage.
- impellers with balancing holes to minimize the axial force acting on the main bearing.
- an inducer for increased suction performance. The inducer increases pressure in the first impeller and minimizes cavitation together with securing a lower NPSH value.

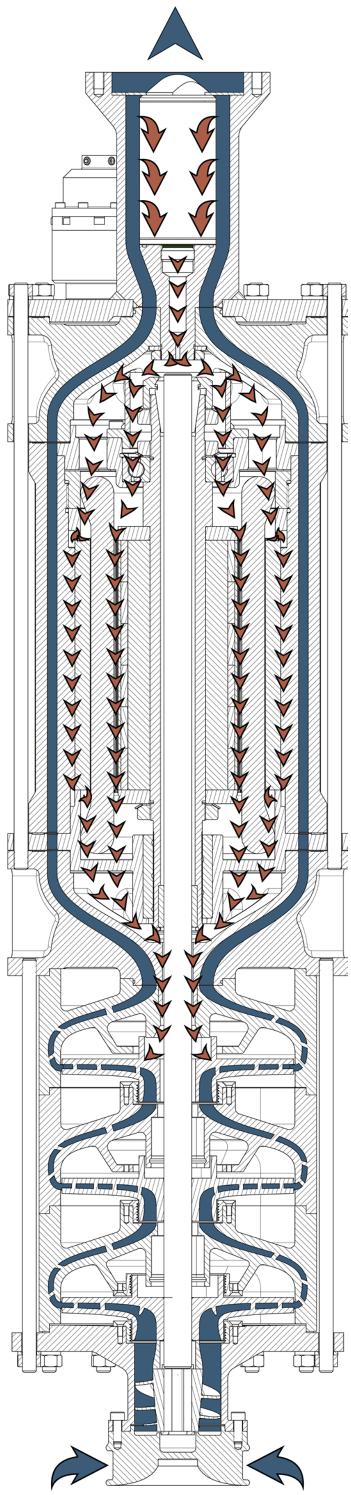


Figure 3

Svanehøj CS fuel pump data

Min. design temperature: -200°C
Design flow: 4-16 m³/h
Design heads: 2-stage 240 mlc, 3-stage 320 mlc, 4-stage 400 mlc
Head per stage: 80 mlc
Speed: Variable 3000-6000 rpm

Control method: VFD
Rated motor current: 42 A
Rated motor power output: 20 kW
Electric motor type: Permanent magnet, derated for VFD
Filter: Internal filter for cooling and lubricating flow
Filter type: Self-cleaning under operation

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