Introduction of the Design Features of Cryogenic Pumps and Expanders for FSRU Applications

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Abstract

This paper describes the design enhancements of cryogenic pumps and expanders for the floating liquefied natural gas (LNG) vessels applications, such as floating storage regasification units (FSRU). The conceptual design of two-phase expander is also discussed for power recovery applications.

1. Introduction

Traditionally, natural gas liquefaction plants, receiving terminals and storage tanks are constructed onshore as large scale structures. However, offshore platforms, such as FSRU (Floating Storage Re-gasification Units) and FPSO (Floating Production, Storage and Offloading) units are becoming more common due to their flexibility, portability and environmentally friendly technology. Floating units are also known to be a cost effective solution for liquefaction and storage applications.

Floating units are much more compact but can be complex in design due to being a floating structure. As a result, the conventional design of rotating equipment may not be suitable for these applications. Since the rotating equipment is installed on an offshore floating platform subject to direct dynamic motion, the resulting forces due to these motions should be taken into consideration in the design of the pump and its system components. The floating motion can be in any direction and type such as rolling, pitching, yawing, heaving, surging and swaying mode.

In order to minimize the risk of deterioration and premature failure of the rotating equipment the design of the pumps and expanders are enhanced with minimum increase to the pump or expander size.

2. Cryogenic Pump Basic Design

The conventional re-gasification process for onshore and offshore plants requires send-out pumps with relatively high pressures. Column mounted in-tank pumps move LNG from the storage tanks to the HP send-out pumps which in turn feed high pressure LNG to the vaporizers.

Ebara’s typical suction vessel mounted high pressure cryogenic LNG pump is shown at Figures 1 and 2. The entire pump and motor assembly are contained within a suction vessel built to the appropriate pressure vessel code for each application, making the installation safe, simple and reliable. The suction vessel functions as the outer pump casing. It is fabricated with a suction nozzle, welded couplings (for drain and liquid level indication), support brackets, a head plate with discharge nozzle, a conduit for electrical cables and a vent nozzle. The result is a compact, lightweight, uncomplicated installation. This design has proven to be extremely reliable in send-out

systems which require large, multi-stage pumps to perform on a continuous, 24 hour-per-day basis.
There are specific design features these high pressure pumps offer. The Main ones are as follows:

- The single piece shaft with submerged electrical motor.
- Thrust Equalizing Mechanism (TEM) to balance the axial trust load.
- Product lubricated cryo-special deep groove ball bearings to support the rotating assembly.
- Coolant return lines to maintain coolant flow through the submerged motor.

Figure-1 Typical Vessel Mounted High Pressure Pump during removal from the vessel.

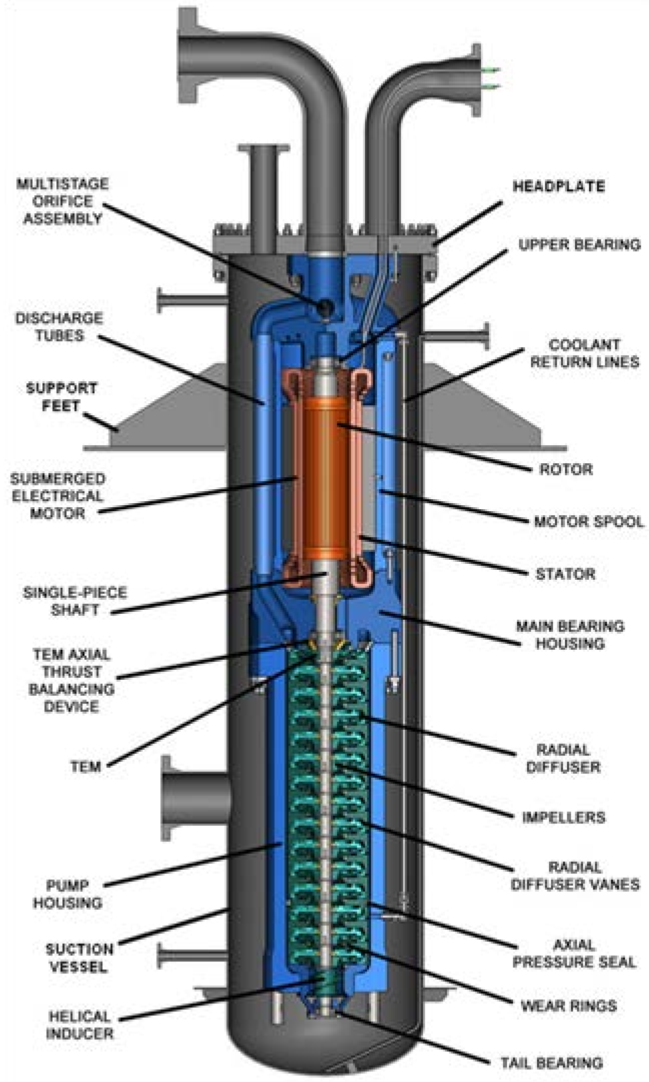

Figure-2 Cross Sectional View of Typical Suction Vessel Mounted High Pressure Pump.

As shown at Figure-2, the cryogenic pump is suspended by the headplate and installed in a suction vessel that is filled by LNG. The cryogenic pump and its motor are submerged completely in LNG.

In the case of onshore applications, the foundation of the vessel is stable and the suction vessel is only subjected to the nozzle loads and loads due to normal pump operation.

3. Design Enhancements of Cryogenic High Pressure Send-out Pumps for Offshore Applications

For offshore applications, floating unit or ship motions must be considered in the design of high pressure send-out pumps. The pump suction vessel and pump itself are always subjected to loads due to the continuous motion of the structure. Therefore, the system and pump component designs are enhanced to minimize the ship motion effect to the pump operation and reliability of the unit. These enhancements are discussed in the following sections.

3.1 Suction Vessel support

The suction vessel for high pressure applications often has three or four feet welded to the vessel body, which support the complete pump assembly with the suction vessel. The complete assembly is bolted to the main structure by these support feet. Due to ship motions, suction vessel and its support feet may be subjected to additional loads. The magnitude of this additional load depends on the acceleration of the main structure (floating unit/ship) and the location of the pump and vessel on the main structure.

Since the high-pressure send-out pump structure is relatively long and narrow, loads due to ship motions may result in increased vibration and stress. To reduce the stress and eliminate the vibration due to ship motion, the lower side of the suction vessel is equipped with equally spaced support pads as shown in Figure 3.

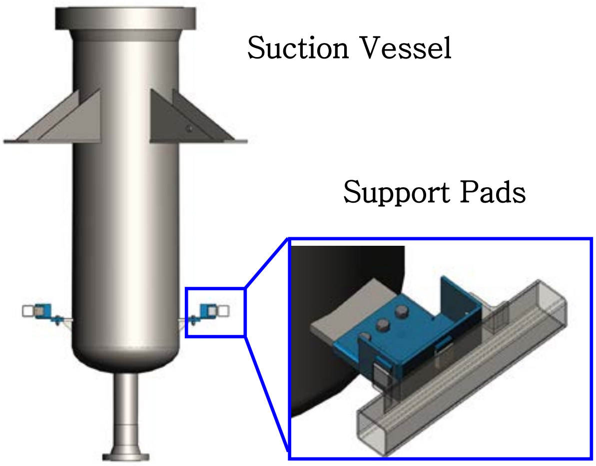

Figure 3 – Vessel Mounted High Pressure pump with lower support pads.

3.2 Pump Casing Support

Since the pump assembly is suspended from the headplate, the pump is only fixed from the upper end. The load applied on the headplate is due to pump assembly weight and the suction pressure acting in the opposite direction to the pump weight. Both loads are in the vertical direction, for onshore (landbased) applications. However, for offshore applications, the resultant force will be off centre. The pump acts as a cantilever beam and rigidity reduces. Pump casings may be excited due to lateral forces. To increase the stiffness of the pump assembly casings, the pump is also mounted to the vessel/headplate from the lower end as shown at Figure-4. This greatly increases the stiffness and the natural frequency of the casings, where the ball bearings are installed. The lower support also reduces the stress caused by the bending moment due to side (radial) forces acting on the headplate-to-pump assembly bolting and the upper most casing.

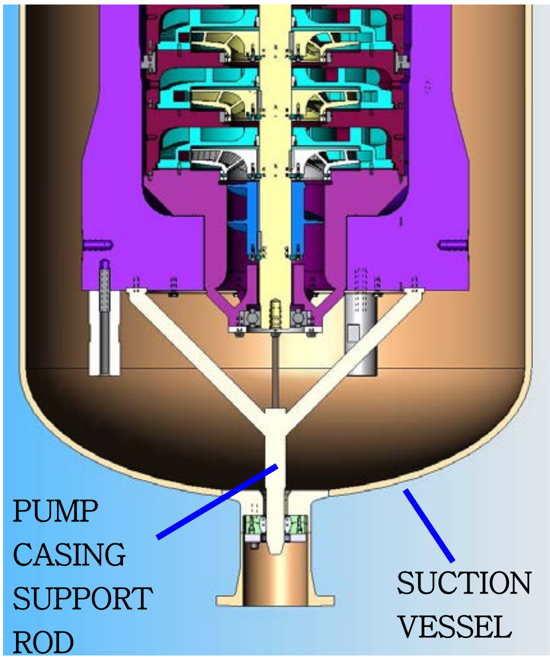

Figure 4 Pump casing support shown with the suction vessel.

3.3 Pump Shaft Support

During normal operation of the pump, the shaft with rotating assembly is supported axially by the TEM and bearings are lubricated by pumped product. Once the pump is shut down, the weight of the shaft and the rotating assembly are supported by the main bearing only. If there is enough acceleration due to ship motions to excite the shaft and allow it to rotate, the main bearing will be spinning with no lubrication. If this condition exists for an extended time, the main bearing can deteriorate prematurely.

To prevent unwanted spinning of the shaft in the standby condition, a shaft stabilizer (support) can be implemented. This device simply locks the shaft and does not allow any rotation when the pump is off.

Figure 5 and 6 show the shaft stabilizer for high pressure pump applications.

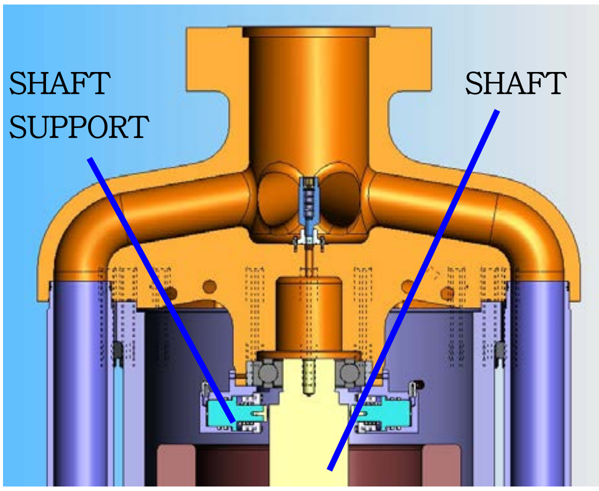

Figure 5

The device is controlled by using pneumatic pressure with flexible lines and instrumentation tubing as shown in Figure 6.

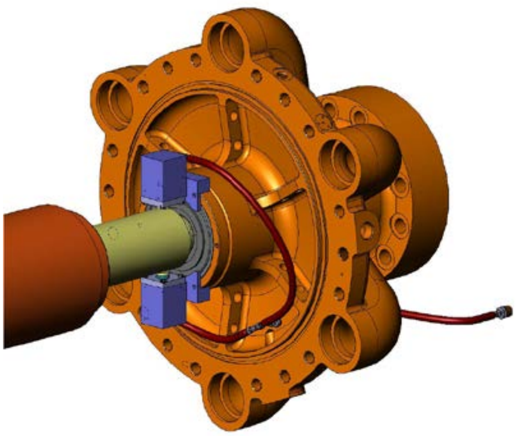

Figure 6

4. Power Recovery System

The Rankine Cycle is a thermodynamic cycle which converts heat into work. The heat is supplied externally to a closed loop with a particular working fluid, and also requires a heat sink. This cycle generates about 80% of all global electric power. The Rankine Cycle is shown using a typical Mollier diagram with the pressure p over the enthalpy h.

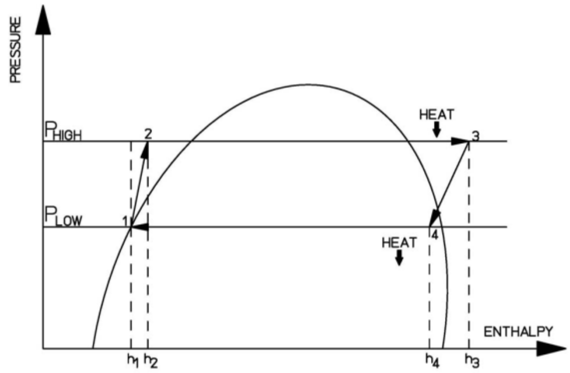

Figure 7

The ideal Rankine Cycle [3] with single phase vapour expansion consists of the following four process steps (Figure 7):

- 1→2 Isentropic compression of the liquid fluid to a high pressure in a pump
- 2→3 Constant high pressure heat addition in a boiler to completely vaporize the fluid
- 3→4 Isentropic expansion in a turbine gas expander to low pressure
- 4→1 Constant low pressure heat rejection in a condenser to re-liquefy the fluid

Two-Phase Rankine Power Cycle

The two-phase fluid ideal Rankine Cycle with liquid-vapour two-phase expansion (Figure 8) consists basically of the same four steps, with the difference that the pressurized liquid is only partially vaporized thus remaining within the saturation dome and the isentropic expansion of the liquid-vapour mixture is achieved in a two-phase fluid expander.

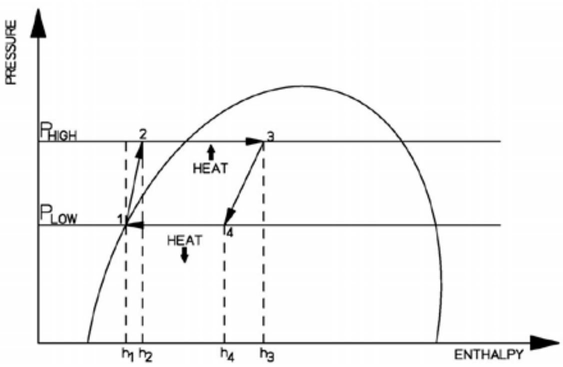

Figure 8

For power recovery using a two-phase fluid Rankine cycle in LNG regasification plants, several field proven working fluids are available and used in similar applications. To achieve a higher efficiency the working fluid is passed through two heat exchangers and one 'Pump Two-Phase Expander Generator' (PTPXG), a compact assembly of a pump, a two-phase expander and an induction generator integrally mounted on one rotating shaft.

Figure 9 presents the schematic of the equipment using the Rankine power cycle with two-phase expansion following the four described process steps.

- 1→2 With work input, the pump, P, pressurizes the liquid single phase working fluid from low pressure to high pressure.
- 2→3 The pressurized single phase working fluid is heated and partially vaporized by passing through the generator, G, and the heat exchanger with the heat provided by sea water or other heat sources,
- 3→4 The pressurized and heated two-phase saturated working fluid expands from high-pressure to low pressure across the two-phase expander, T, generating a work output.
- 4→1 The low pressure two-phase saturated working fluid passes through a heat exchanger with the heat sink, the LNG for regasification. The working fluid condenses from saturated liquid-vapour two-phase to non-saturated liquid single phase.

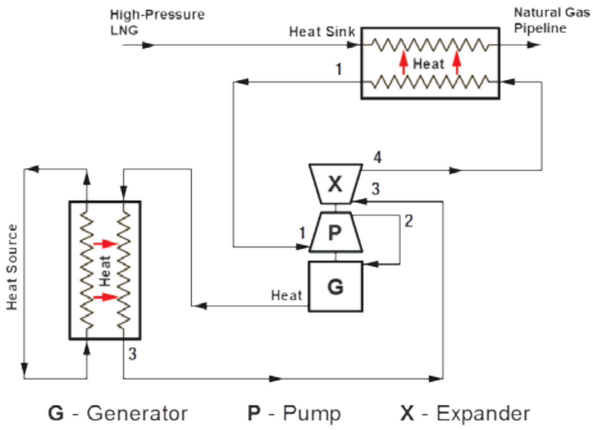

Figure 9

The compact assembly of a Pump Two-Phase Expander Generator (PTPXG) is demonstrated in Figure 10 and Figure 11 as two different designs of PTPXP. In Figure 10 the working fluid enters the pump at the lower inlet nozzle, exits the pump to the side and passes through the generator housing cooling the generator, thus recovering the heat losses of the generator. After passing through the heat exchanger with the heat source, the saturated working fluid expands across the two-phase expander generating work, driving the pump and the induction generator.

In the modified design shown in Figure 11, the pressurized single phase fluid passes directly from the pump through the generator housing, thus cooling the generator, and then exits to the side to pass though the heat exchanger. In both design versions the leakage flow through the seal and the axial thrust is minimized due to equal pressure on both sides of the seal and opposing directions of the axial thrust forces.

The following advantages of the compact assembly PTPXG can be realised

- The expander work output is larger than the pump work input and the difference in work is converted by the generator into electrical energy.
- The losses of a separate pump motor are eliminated.
- The losses of the induction generator are recovered and used as heat source to heat the working fluid in addition to the heat from sea water and other heat sources.

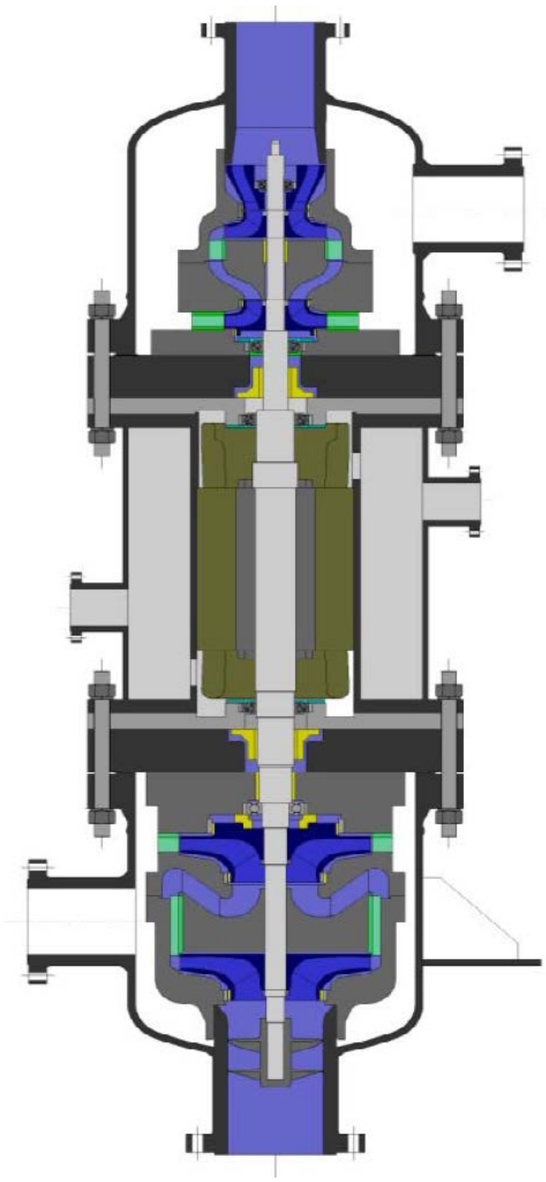

Figure 10

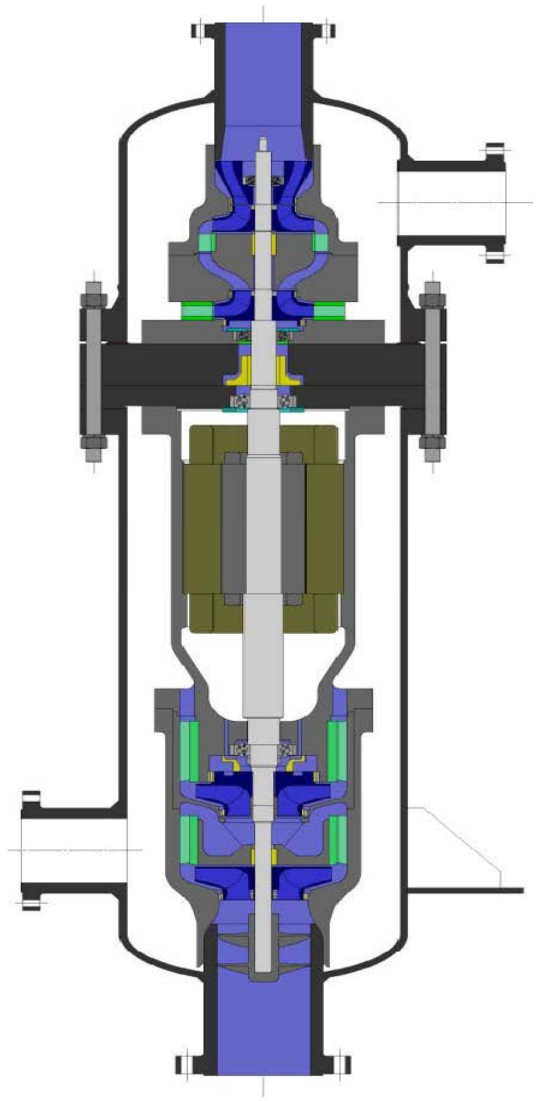

Figure 11

- Any leakage of the working fluid is minimized due to equal pressure on both sides of the seal, and small leakages are within a closed loop and occur only between pump, expander and generator.
- The axial thrust is minimized due to opposing directions of the thrust forces decreasing the bearing load and increasing the bearing life.

Conclusions

These enhancements of the Cryogenic high-pressure send-out pump have been applied before and are available for whichever offshore application is specified.

The presented Rankine power cycle, incorporating a compact design consisting of a pump, a two-phase liquefied gas expander and an induction generator, integrally mounted on one single rotating shaft, offers efficient and economical power recovery for floating LNG regasification units.

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