

*Michael Cord, Ebara International Corporation, USA, looks at the technological history of submerged motor pumps in the LNG industry.*

## THE HISTORY OF SUBMERGED MOTOR PUMPS

With nearly 100 liquefaction trains online, over 300 LNG carriers in service, and over 60 import terminals, it is hard to imagine a time when the global LNG industry did not exist. Though the industry's roots can be traced back to 1912 with the first LNG plant in West Virginia, USA, it is only a little over 50 years since regular commercial exports began. With the rise of the LNG industry, pump technology rose along with it giving birth to a new breed; the submerged electrical motor pump (SEMP). This article highlights the major milestones in the evolution of SEMPs and explores the major technical aspects of this unique machine.

### **The beginnings**

Godfrey Cabot received a patent on 18<sup>th</sup> May 1915 for 'Means of Handling and Transporting Liquid Gas', but it was not until the early 1950s that the transportation of liquefied gas by marine vessel was seriously considered. Early feasibility studies began in Chicago but soon work began on the other side of the Atlantic as companies in the UK, Norway and France saw the economic benefits as well. The US got there first with the commissioning of the *Methane Pioneer* in 1958 and the delivery of its first cargo to the UK in January of the following year. The ship used existing technology as much as possible and this is evident in its main cargo pump; a 1000 gal./min. deepwell pump installed in each tank.

Deepwell pumps proved to be difficult in LNG service due to the temperature differential between the tank and external atmosphere causing the shaft to bind. This could be solved if there was no need to separate the pump from the motor. In other words, the motor should be submerged along with the pump. The nature of LNG and its storage made this possible. The tanks were inerted with the removal of oxygen. Also, hydrocarbons are a dielectric fluid, meaning that the electrical cables and the motor itself can be safely submerged and surrounded by LNG. The J.C. Carter Company supplied the first submerged motor pump to the French vessel *Beauvais* in 1961.

By the 1970s, SEMP's were commonplace onboard LNG carriers (Figure 1). They also began to replace various external motor pumps. SEMP's have a major safety advantage over their external motor counterparts in that there is no need for a shaft to penetrate the tank, thus eliminating mechanical seals. Further development included a submersible pump that was retractable and could be installed from the top of the LNG storage tanks, which meant that no connections were required below the liquid level. Another advantage is by integrating the pump and motor into a single unit with a common shaft, coupling and alignment issues are removed.

## SEMP technology

### Motor

The major component of SEMP's is, of course, the motor itself (Figure 2). The motors are of three phase, squirrel cage, induction design. The stator is fabricated from silicon iron laminations and form or random wound copper windings. The windings are protected with an epoxy insulation applied via



**Figure 1.** A submerged motor cargo pump being installed inside an LNG carrier.

a vacuum impregnation process to remove air pockets during the curing process. The rotor is also made from silicon iron laminations and then completed with aluminium bars between the two aluminium end caps. The end caps can be cast in place or prefabricated. The major consideration is the tensile stress induced in the bars as the rotor is cooled to cryogenic temperatures. The differential thermal contraction properties of the aluminium bars and the silicon iron laminations must be carefully considered by the motor designer.

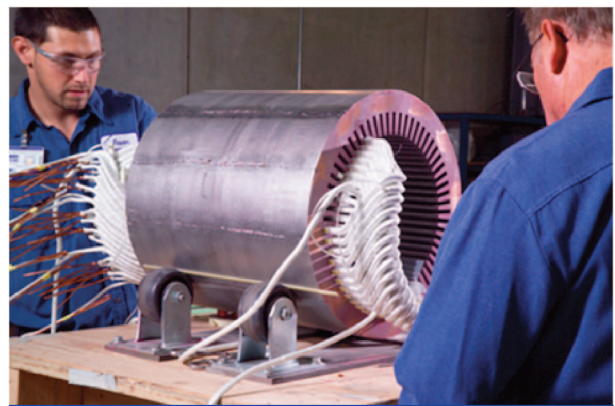
The major advantage of a submerged motor is safety. By mounting the motor on a common shaft with the pump hydraulics, the entire unit is submerged; the motor 'air gap' being filled with the liquid gas. This eliminates the need for a mechanical seal and its potential leakage hazard. Also, with the motor submerged in the liquid it is isolated from the atmosphere in an oxygen free environment. A lack of oxygen means the motor is not located in a hazardous area, negating the complex requirements of ATEX and other hazardous area certifications.

Motors can range from 5 kW up to nearly 3 MW with voltages from 380 V up to 6.6 kV. The operating frequency can be 50 or 60 Hz to suit the local power supply. The operating speed can be 2, 4 or 6 pole and operation via a variable frequency drive (VFD) is not uncommon. Additionally, by using the cryogenic liquid as a cooling medium, the physical size of a submerged motor is less than half that of an equivalent air cooled motor (Figure 3). The compact nature of submerged motor pumps provides great advantages to the civil engineering aspects of plant design.

### Bearings

As with any rotating machine, the bearings are a vital component in the overall design. Due to the cryogenic temperatures, standard sealed bearings cannot be used for fear of the grease freezing. Thus, open cage style, product lubricated bearings are the norm. A small portion of the pumped fluid is routed through the bearing to both cool and lubricate it. Early testing showed that thrust or angular contact bearings did not hold up well in cryogenic service. The reason is due to the low viscosity of liquid hydrocarbons and the low boiling point of the fluid. Heat added to the cryogenic liquid due to friction from an axial load would vaporise the liquid and the bearings would fail very quickly. By using the pumped fluid to lubricate the thrust bearing, under thrust loads the liquid could not provide a sufficient film layer between the balls and races. This led to premature spalling and a reduction in bearing life.

Development led to the use of deep groove radial ball bearings, which is now the standard adopted by almost all SEMP manufacturers. Bearings are made from either low alloy steel (such as 52100) or high carbon stainless steel (such as 440C). The cage is made from various graphite impregnated thermoplastic materials, often of proprietary design. Other materials have recently been investigated to cope with the widening application for SEMP's. In the late 1990s a hybrid material bearing featuring silicon nitride ( $\text{Si}_3\text{N}_4$ ) ceramic balls was installed in an SEMP for methane



**Figure 2.** Submerged electric motor being manufactured.

wash service. The hard ceramic balls mated to the steel raceway resulted in a 'self healing' effect. The balls continuously burnish the raceways to maintain a high level finish and limit surface damage from debris. The hybrid bearings are more tolerant of low viscosity liquids and have shown improved wear resistance and fatigue life; features that have led to their increased use in the recent years.

### Thrust balancing

The poor performance of product lubricated thrust bearings in cryogenic liquids results in the need for other means to balance the axial thrust loads. All SEMP manufacturers have adopted some form of hydraulic balance system to accomplish this. The first machines used technology derived from overhung barrel type pumps; namely a balance disk or drum located at the top of the pump. While effective, the early marine cargo pumps experienced difficulty in eliminating the net thrust load over the entire operating range.

1973 saw the emergence of Cryodynamics and its introduction of a revolutionary balancing system where the balance disk/drum at the top of

the pump was eliminated. Thrust balancing was transferred to the last stage impeller and achieved via the incorporation of two orifices in series: a fixed radial orifice and a variable axial orifice. The fixed orifice was created by an offset wear ring at the upper shroud of the impeller and the variable orifice was achieved with a stationary thrust plate in conjunction with an axial 'floating' rotating assembly. This arrangement proved both versatile and reliable. By the mid 1980s, Cryodynamics had established itself as the market leader and today, the vast majority of SEMPs sold use its balancing system.

### Hydraulics

The hydraulic designs of SEMPs have evolved from standard centrifugal API type vertical inline pumps. The diffusion is accomplished with multi vaned diffusers rather than a volute casing. The diffusers can be axial flow (to maintain smaller diameters) or radial flow (to maintain shorter stage lengths). The impellers are of radial or mixed flow (Francis) type, closed shrouded design and the hydraulic stages are radially split. Up to 20 stages or more are possible to suit the service requirements. Typically, the first stage is a high specific speed axial flow inducer, used to improve net positive suction head required (NPSHr) performance. In the first units, these inducers were a fan blade design. By the 1970s, high solidity spiral wound inducers were introduced from the rocket fuel pump industry. Today, inducer designs vary in hub cross section, vane pitch, number of vanes and other geometries to suit particular performance characteristics. Suction specific speeds can range from as low as 40 000 to over 100 000 as each design has its own advantages and disadvantages for various types of pump service.

With the motor mounted on a common shaft with the pump hydraulics, the rotating components become a single assembly. This assembly can be designed to fit any pump configuration. SEMPs can be mounted directly inside a tank (as in marine carriers), retractable in tank mounted (as in storage tanks), or mounted in self contained pressure vessels (as in product or transfer pumps). The configuration is independent of the hydraulic design, allowing a wide range of adaptability.

As the industry has grown, so have the pump hydraulics in order to keep up. Liquefaction trains have grown from less than 1 million tpy at Kenai in 1969 to 7.8 million tpy at Qatargas 2 in 2008; marine carriers have grown from 34 500 m<sup>3</sup> of the *Methane Princess* in 1964 to 266 000 m<sup>3</sup> with LNG carriers such as the *Mozah Q-Max* in 2009. Such rapid growth has resulted in the continuing expansion of the SEMP performance envelope. Today's pumps can now achieve capacities of up to 3000 m<sup>3</sup>/h and over 3000 m of head.

### Applied technology

SEMP technology has been applied to other machines in the LNG industry as well. The rise of cryogenic liquid expanders/turbines is an excellent example. Liquid expanders are a fairly recent addition to LNG liquefaction

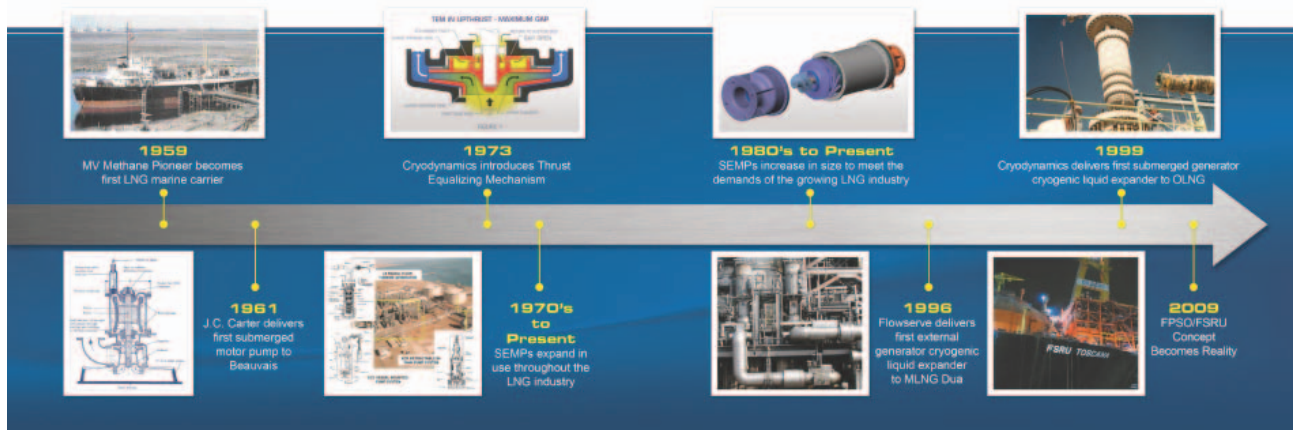
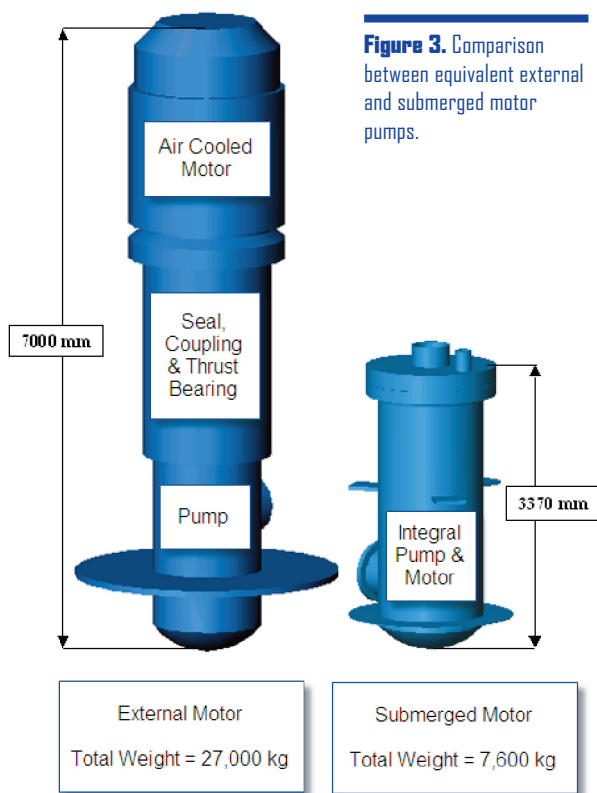


Figure 4. Submerged motor pumps timeline.

trains. They take the place of a Joule-Thomson valve for the isentropic expansion phase of the refrigeration cycle; be it APCI, Linde, DMR process, or CPOC. Such a machine can increase the train's LNG production by 3 - 5%, while also generating electrical power.


The first cryogenic liquid expander to operate in an LNG liquefaction train was delivered by Flowserve in 1996 to the MLNG Dua plant in Bintulu, Malaysia. The machine featured variable geometry wicket gates and an external air cooled generator. At this time, Cryodynamics (now a division of Ebara) applied SEMP technology to develop a submerged generator liquid expander. This machine was delivered to O LNG in Sur, Oman in 1999. Following the same principles proven in their pumps, the Cryodynamics version featured an integral generator, fixed geometry axial nozzle vanes, and operated as a variable speed machine. This was accomplished by using a variable speed constant frequency (VSCF) regenerative drive engineered by Cegelec Alstom (now Converteam). The drive unit was essentially two invertors mated through a common DC voltage link. The expander can operate at various shaft speeds and generator frequencies, yet still maintain a constant frequency power input to the local power grid. Today, over 80% of all cryogenic liquid expanders in operation are of submerged generator design.

Another new frontier for the LNG industry and SEMPs is floating technology. Existing LNG carriers are converted into product handling and storage facilities. Floating production storage and offloading (FPSO) units are converted vessels that can be moored near small at sea gas wells. The LNG can be processed and liquefied onboard the vessel and then offloaded to another vessel for transport. At the other end of the chain, floating storage and regasification units (FSRU) receive LNG from a carrier moored alongside. The product can be stored and then pumped to a vaporiser onshore via an undersea pipeline. SEMPs are ideal for floating service due

to their compact size, given that space onboard the vessel is quite limited. There are several projects currently in process. To date there are no LNG FPSO units yet in service. However, *Golar Spirit*, the first FSRU, began service off the coast of Brazil in January, 2009 and the next FSRU, *Toscana*, is nearing sea trials before its planned service off the coast of Livorno, Italy. Both vessels feature SEMPs for their high pressure send out pumps.

## Conclusion

The application of SEMPs has expanded from the humble beginnings of the first LNG marine cargo pumps. The improved safety aspects as well as the smaller footprint has allowed SEMPs to take over what was once the domain of external air cooled motor pumps for many liquefied gas applications. SEMPs are now standard equipment for such varying services as loading, circulation, marine gas fuel and send out used for LNG, LPG, ethylene, propylene, ammonia and many other liquefied gases. They can be found in liquefaction trains, marine carriers, regasification plants, peak shaving plants, fertiliser plants and nitrogen rejection plants. They handle liquids as diverse as methane, nitrogen and ammonia; and they can pump liquids from -195 °C to +45 °C.

LNG is the fuel of today and the foreseeable future. Thanks to rise of this industry, pumping technology has advanced and will continue to do so. 

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