

TUTORIAL ON CRYOGENIC SUBMERGED ELECTRIC MOTOR PUMPS

by

Steve Rush

Sales and Service Manager

and

Lonn Hall

Senior Project Engineer

Ebara International Corporation

Sparks, Nevada



Steve Rush is the Manager of the Sales and Service Department for Ebara International Corporation, in Sparks, Nevada. He has more than 19 years' experience in the design, service, and sales of submerged motor cryogenic pumps. He is a long-standing member of ASME, and has written several articles and papers on various pump related subjects.



Lonn Hall is a Senior Project Engineer for Ebara International Corporation, in Sparks, Nevada. He has been with Ebara International Corporation, Cryodynamics Division, for more than six years. He graduated with a B.Sc. degree (Mechanical Engineering, 1988) from the University of Wyoming and is a registered Professional Engineer in the States of Nevada and Washington.

ABSTRACT

The cryogenic submerged electric motor pump described here is a unique centrifugal pump design specifically developed for handling cryogenic fluids such as liquefied natural gas (LNG), liquefied petroleum gas (LPG), liquid ethylene, propylene, ethane, and various other cold liquids. The design has evolved into a very reliable pump, which uses practical solutions to many of the traditional problems that centrifugal pump manufacturers experience. This paper discusses the original design concept and development as well as the typical uses of cryogenic submerged electric motor pumps built for the liquefied gas industry. The paper describes the way the fluid is routed through the pump and used for bearing cooling and lubrication, the cooling of the motor, cavitation, and the relationships between the pump and system.

INTRODUCTION

The liquefied natural gas business was in its infancy in the early and mid 1960s, and the handling and transport of liquefied gas from the exporting country to the importing country were required. The first application for the submerged electric motor cryogenic pump was a cargo pump onboard a liquefied natural gas transport ship. Traditional methods of pumping cryogenic fluids used an external motor with the shaft penetrating through a headplate, extending down into the liquid to the hydraulic end. There were serious problems at the penetration of the shaft in trying to provide

a dynamic seal that would not leak, mainly due to the differential temperature between the very cold cryogenic liquid and the outside atmosphere. Another inherent problem was encountered when installing a pump onboard a ship where the motor was located at the top of the tank but the hydraulic end was at the bottom of the tank, with a significant distance between them. This required a very long shaft to extend from the motor to the pump. The alignment of the shaft between the motor and pump was very difficult due to the length and differential shrinkage between the materials.

Due to the inherent problems with traditional design concepts, the idea of completely submerging the motor and pump together in the pumped cryogenic fluid was born.

CRYOGENIC SUBMERGED MOTOR PUMP DEVELOPMENT AND CURRENT DESIGN

Most cryogenic liquids are nonconductive and the complete motor can be submerged in the liquid and operated without fear of short circuit in the motor windings. This, coupled with the fact that there is no oxygen present within the vessel containing the hydrocarbon liquid, provides a very safe environment for a completely submerged pump design in the hydrocarbon liquid.

By submerging the pump and motor in the liquid, rotating shaft seals with their inherent leakage problems are eliminated. This is one of the most important aspects that led to the current designs, particularly in applications handling hazardous liquids.

When the first designs were built, they were extremely simple machines with an outer casing, motor, shaft, and impellers (Figure 1). One of the first problems encountered was due to the instability of a cryogenic fluid when heat is added, causing vaporization of the liquid. The first designs also had bearing problems due to axial thrust loads. The thrust loads caused enough friction and heat to vaporize the liquid, thus removing the cooling and lubrication to the bearings.

The next generation provided a thrust balancing mechanism similar to that used in many other centrifugal pump types in order to reduce the thrust load as much as possible. This single design change allowed the submerged cryogenic pump to operate for very long periods of time with little or no maintenance.

After the first designs were installed and operated, experience showed several benefits of submerging the motor and pump in the cryogenic liquid. The rotating seals previously used that were prone to leakage were eliminated, and the bearings and motor worked very well in the liquid. The physical size of the motor was reduced significantly due to the excellent cooling characteristics of the cryogenic liquids compared to an external air-cooled motor. Even though cryogenic liquids have low viscosities and are poor lubricants, the cold environment can remove any heat so efficiently that the bearings work very well. Another benefit was the elimination of alignment problems, since the pump and motor were built together on a common, single shaft.

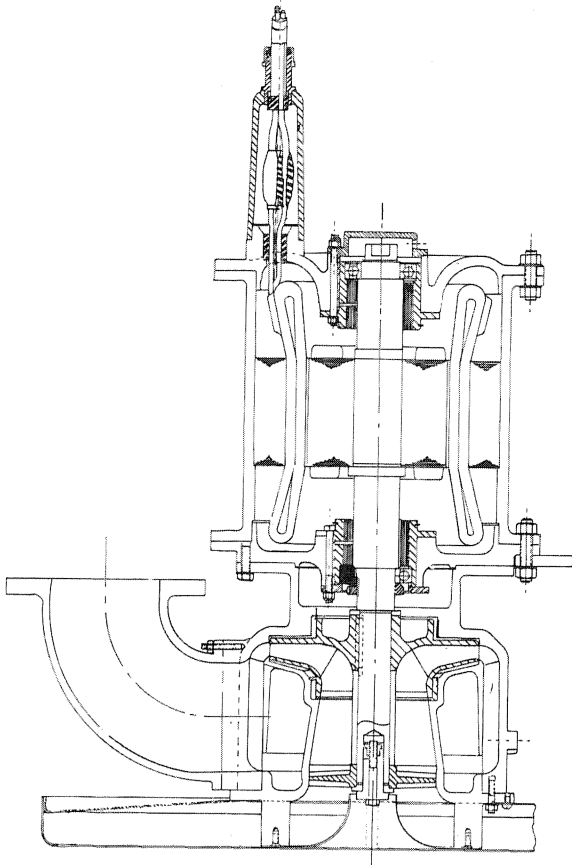


Figure 1. Early Marine Submerged Cryogenic Pump.

Initial designs balanced the axial bearing thrust loads with traditional methods such as equalizing holes in the impeller eye or balance drums. Some that had very light loads used no balancing method at all. These methods proved mostly unreliable and bearing failures were relatively common.

In the early 70s, a new design was developed that used a very simple, two-orifice method of thrust balancing (Figures 2 and 3). By taking a portion of the impeller discharge stream through a back wear ring (fixed orifice), and then routing the liquid through a radial gap between the back of the impeller and a stationary plate (variable orifice), a thrust balancing system was achieved that provided very good damping characteristics. The design could also automatically adjust itself throughout the flow range of the pump. The bypassed fluid continues through the lower bearing, then up into the motor cavity for cooling. Since this bypassed fluid is always circulating at a constant rate, even at off-design conditions, the thrust balancing system and bearing and motor coolant continue to operate properly.

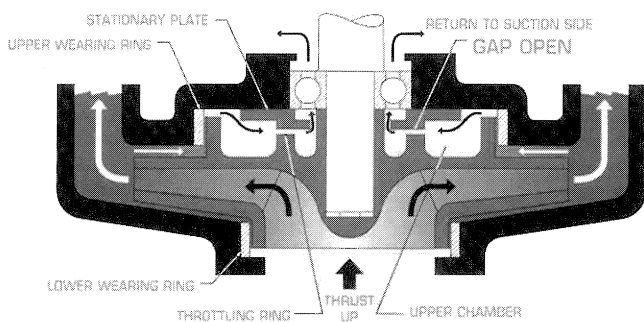


Figure 2. Modern Thrust Balancing Design, with Gap Open.

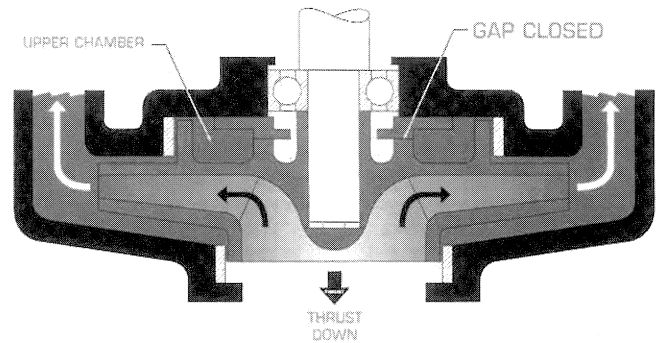


Figure 3. Modern Thrust Balancing Design, with Gap Closed.

Most designs also incorporate an inducer, or axial impeller, in the inlet in order to improve the pump-down capability or NPSHR of the pump. The inducer allows the pump to reduce liquid stock levels down to extremely low levels. This is a very important design feature to help ensure vapor-free liquid enters the pump.

The design of the inducer, impeller(s), and diffuser(s) use conventional practices as any other centrifugal pump designs, but the designer must always be conscious of pressure drops in the pump to prevent localized flashing or vaporization. Since the liquids being pumped are very close to their boiling temperature, any reduction in the pressure acting on the liquid will cause the liquid to drop below its vapor pressure, resulting in vapor generation or boiling.

One interesting point that has been discovered is the lack of cavitation damage that is normally associated with water or other noncryogenic liquids. In a water pump, cavitation can cause severe pitting of the impeller vanes when the liquid vaporizes and implodes. In a submerged cryogenic pump, this same damage is almost nonexistent, due to the low mass and lower pressure energy associated with vaporization and subsequent vapor collapse.

The cryogenic submerged motor pump design has developed into a vertical diffuser type design. This has proven to be the most effective design for the pump as it takes advantage of ensuring vapor and liquid can separate. With the pump mounted vertically, with the inlet near the bottom of its vessel or tank, any vapor will rise and go out the vent system rather than entering the pump suction. The pumps can be single or multistage design and although it is not a limit, pumps of this type have been built up to 18 stages. The impellers are a closed, single suction design, which typically incorporate a mixed flow (both axial and radial) or Francis vane type design. The motors are built for both 50 Hz and 60 Hz power, but are also well suited for operation using a variable frequency drive (VFD) and can be operated at various speeds to allow added flexibility. The motors also can be built in two, four, and six pole configurations depending on speed requirements and rotating element size.

APPLICATIONS

Cryogenic submerged electric motor pumps began their history in the liquefied natural gas (LNG) industry, and this has become the most common application. Over the years, the design has found more applications due to its simplicity, reliability, and suitability for various liquids.

The typical liquids that are pumped and their normal (low pressure) operating temperatures are:

- LNG or methane (-162°C , -258°F)
- Propane (-42°C , -44°F)
- Butane ($+0.6^{\circ}\text{C}$, $+33^{\circ}\text{F}$)
- Ethylene (-104°C , -155°F)
- Nitrogen (-196°C , -320°F)
- Propylene (-48°C , -54°F)

- Ethane (-89°C, -128°F)
- Ammonia (-33°C, -28°F)

It should be noted that the word “cryogenic” is applied rather loosely in some cases. For example, at a pressure of 35 bar (508 psi), a liquified petroleum gas (LPG) pump may operate at a temperature as high as +40°C (+104°F).

The growth in the use of this pump design is due to its adaptability to various methods of installation. The basic types are:

- *Vessel-mounted*—This type (Figure 4) is widely used as it most easily fits in piping systems. This type of pump is also widely used in pressurized storage tanks.

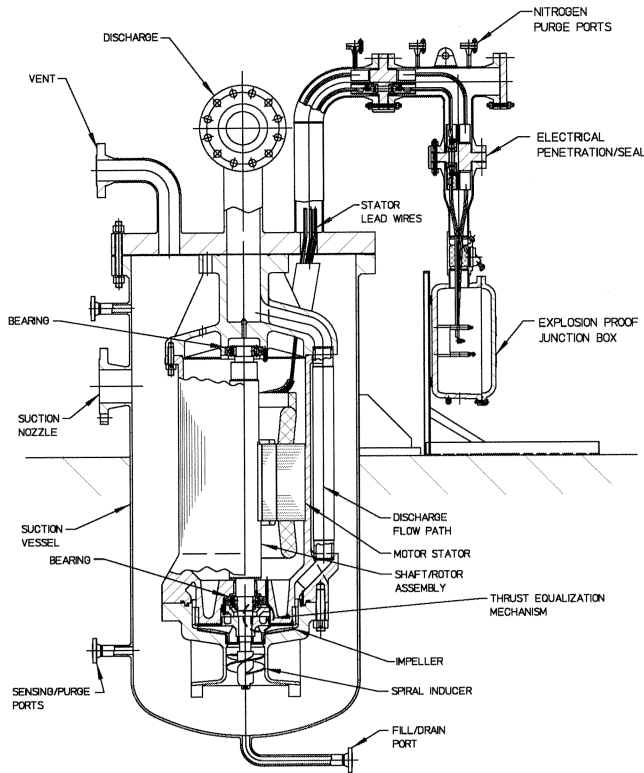


Figure 4. Modern Vessel-Mounted Submerged Cryogenic Pump.

- *Retractable in-tank*—This type (Figure 5) is used in large low-pressure storage tank systems where a side penetration in the tank is not desirable. The pump can be lowered into the tank in a pipe column and seated in a suction valve at the bottom of the tank. The pump discharges through ports located just above the last stage impeller. The liquid eventually fills the column and full pressure is developed once the liquid reaches the control valve located in the discharge line from the column on the roof of the tank.

- *Marine or fixed*—This type (Figure 6) is used mainly for shipboard use and is fixed in a support system located at the bottom of the tank. The discharge piping attaches directly to the top of the pump, then up and out the tank roof.

Various adaptations to the three basic types above have been used extensively in many other applications.

When the pump is used in a piping system, it is installed in its own suction vessel (Figure 4), which is normally made from austenitic stainless steel for temperatures below -60°F (-51°C), or low carbon steels above that temperature. The suction vessel takes the loads of the piping and structural system and thus virtually removes any outside forces from affecting the pump itself. It also eliminates any requirement for alignment as the pump bolts only to the underside of the headplate of the suction vessel. Another advantage of the suction vessel is that the pump can remain in the liquid and ready for

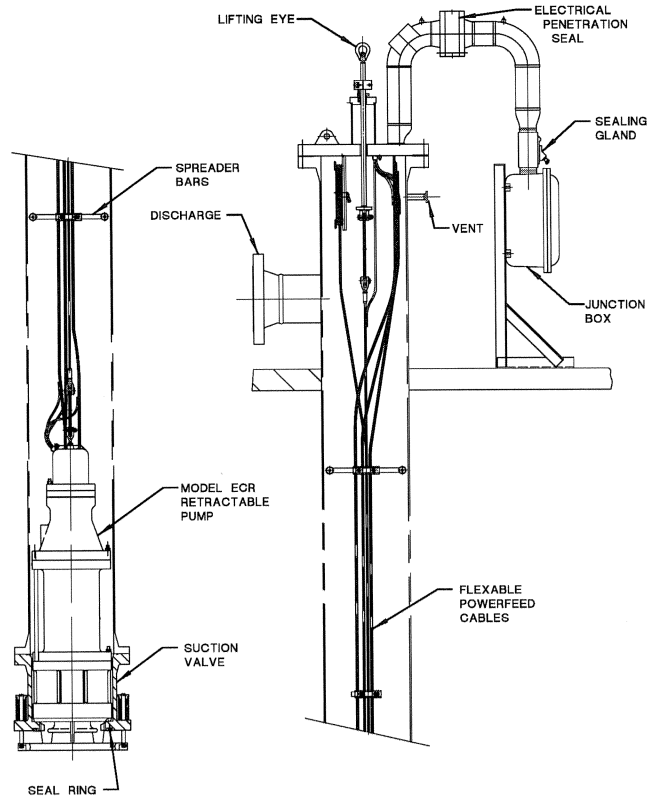


Figure 5. Retractable Type Pump.

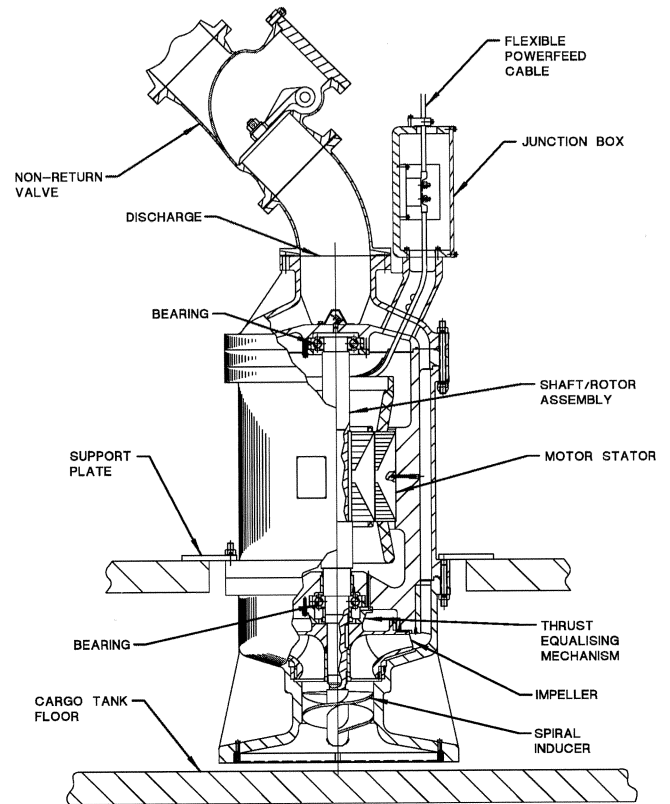


Figure 6. Shipboard or Marine Type Pump.

operation at any time. The vessel and surrounding liquid also very effectively dampen the noise from the pump, eliminating any further need for noise reduction by other means.

The retractable type pump has become very common for use in large liquefied gas storage tanks. One of the unique features of this design is the suction valve, or "foot" valve. The suction valve allows the installation or removal of the pump into or out of the pump column even with liquid in the tank. The pump can be raised or lowered to close or open the valve without removing the headplate at the top of the column. In this way, the column can be purged with dry nitrogen and inerted to allow safe removal or installation of the pump for maintenance.

The only penetration from the pump to the outside atmosphere is the electrical power leads to the motor. For this, various designs have been used such as fiberglass type insulators with copper studs passing through, as well as ceramic and glass type insulators. The typical design uses two electrical feed-throughs in series for safety in order to meet the National Electrical Code (NEC), as well as most other international codes. The space between the seals is a pipe or conduit that can be monitored for any possible leaks in the primary seal. This same space can also be purged with dry nitrogen gas to prevent moisture from condensing due to the high differential temperature at this location.

Another item that has been recently developed is an armored power cable specially designed for cryogenic use. This cable has several layers of polytetrafluoroethylene (PTFE) tapes applied over multistranded tinned copper wire. The cable is then passed through a heater, which seals the PTFE tape, but still allows excellent flexibility. For outer protection, a braid of stainless steel wire is added. This type of cable is used extensively in applications where a long run of cable is required, particularly for shipboard or large storage tank applications. This new flexible power cable has replaced the previously used mineral insulated (MI) cable that was difficult to work with and had limited voltage range.

The cryogenic submerged electric motor pump is also ideally suited for use with a variable frequency drive (VFD). Since the motor is already designed with a heavy-duty insulation system, it is very compatible and reliable when used with a VFD. The big advantage of using a VFD is the added flexibility in obtaining a very wide range of flows and pressures. A good example of this application is the use of a high-pressure send-out pump that can be used for send-out when operated at higher speed, but can also be used to load truck trailers when operated at low speed. This allows the use of one pump for two very different operating points instead of using two pumps. Many cryogenic submerged pumps are in use today operating with variable frequency drives.

The following provides a more detailed description of some of the uses for cryogenic submerged electric motor pumps:

- *LNG production, liquefaction train*—In LNG liquefaction plants, liquid is produced from raw feed gas in a liquefaction train. Feed gas is sent through the train and is cooled across a series of heat exchangers using a variety of refrigerants. Submerged motor pumps are used to transfer the liquefied gas to storage tanks. Submerged motor pumps are also used to transfer other hydrocarbons (LPG, for example) as they are separated and collected in the liquefaction and processing of the feed gas. The pumps used in the liquefaction train are vessel-mounted type pumps.

- *Low pressure storage*—After the gases are liquefied, they are stored in large low-pressure refrigerated tanks. These tanks have very good insulation systems that allow very little heat in. Because the liquefied gas is stored in such a large volume, it will remain at its saturated temperature for long periods of time. Most modern tanks have only top penetrations and use retractable type pumps installed in columns for transferring the liquid from the tanks. The liquids handled in these systems are typically LNG, propane, butane, ethylene, and propylene. These tanks are sometimes referred to as buffer storage as they allow liquefied gases to be stored in volume and readily available. LNG peak shaving plants also use this type of tank and pump system. The flow and pressure of the pumps used in storage tanks can vary greatly:

- *Loading pumps (large flow)*—Used in the filling of transport ships/barges. LNG loading pumps are normally used in parallel to load LNG ships as quickly as possible. Most LNG carriers being built today have a capacity of up to 138,000 m³ (36.5 million gallons), and normally, it is desirable for the ship to be loaded in about 12 hours. LPG loading is similar, though LPG carriers are smaller in size to the LNG ships and therefore the pumps are somewhat smaller.

- *Transfer pumps*—A low-pressure pump often used to transfer liquid or to feed higher-pressure pumps outside the tank. Normally up to two stages.

- *Circulation pumps*—A low-pressure pump, used to circulate the liquid internal to the tank to prevent rollover and also to circulate liquid through the loading system piping for cool-down prior to loading. Normally up to two stages.

- *High pressure send-out pump*—A high-pressure multistage pump used to feed a vaporizer for gas pipeline or downstream customers. LNG peak shaving plants, receiving terminals, and petrochemical plants all use high-pressure pumps for various applications.

- *Pressurized storage (horizontal or bulleted style tanks)*—Some gases are kept in liquid form but under pressure, which results in a higher temperature than refrigerated storage tanks. Typical liquids used in this application are propane, butane, and propylene. At the higher pressures, the operating temperatures for these liquids can be as high as 40°C to 50°C (104°F to 122°F). These pumps can be of the retractable type, but are more commonly connected to a discharge pipe.

- *LNG/LPG carrier pumps*—The tanks on LNG and LPG carriers normally have two cargo pumps and one spray or circulation pump. The cargo pumps are used in the discharge of the cargo liquid to off-load the ship. The spray or circulation pumps are used for cool-down of the tanks when the tanks are empty, vaporizer feed for ship's power/steam generation, and to bring down dead stock in the tank. Depending on ship design, an optional retractable pump is also installed for cargo removal in emergency cases if all other systems fail.

- *Vessel-mounted process pumps*—

- *LNG send-out or vaporizer feed pumps*—These pumps are normally high horsepower multistage pumps capable of reaching very high pressures. These pumps provide high-pressure LNG to vaporizers so that sufficient pressure and flow are available after the pressure drop through the vaporizer.

- *Ethylene/propylene process pumps*—These pumps are normally multistage pumps that are used in various petrochemical processes or transfer.

- *Supercritical ethylene*—This type multistage pump is normally used for charging a pipeline and is sometimes operated on a VFD to easily adjust to operating requirements.

- *Drain pumps*—Used in the cargo loading system to remove remaining liquid in the piping after a loading cycle

- *LNG fueling pumps*—Normally a relatively small pump coupled with a VFD used for filling vehicles such as automobiles, trucks, and buses

Cryogenic submerged pumps have been supplied for a wide range of flow rates and pressures, with flows ranging from 6 m³/h (26 gpm) to over 3000 m³/h (13,209 gpm), and pressures from 5 barg (73 psig) to over 200 barg (2901 psig) (Figure 7).

Other designs, which have been developed for conductive liquids, are also used in special applications such as liquid ammonia or warm hydrocarbons with entrained water. Since ammonia is highly corrosive and reacts unfavorably with copper, special features can be incorporated to protect the motor and wiring from the liquid. The designs used vary from canning the stator to separating the motor from the liquid via a magnetic coupling.

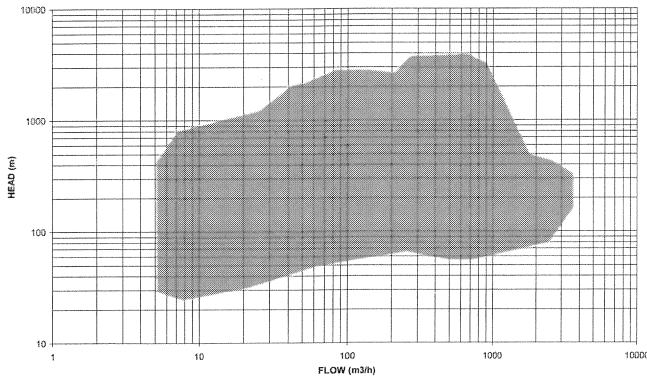


Figure 7. Pump Performance Coverage (60 Hz).

MATERIALS OF CONSTRUCTION AND DESIGN CONSIDERATIONS

Since the pumps described here are normally in a cryogenic environment, the materials of construction are rather specialized when compared with more standard pump designs. The housings and rotating elements (impellers, inducer) are cast aluminum grade A356, which provides very good ductility at low temperatures, as well as good thermal conductivity and stability. Austenitic stainless steels and wrought aluminum (6061, etc.) are also sometimes used for housings and other fixtures. Austenitic stainless steels (300 series) provide good ductility and strength at cryogenic temperatures as well. Shafts are made from various grades of stainless steel, such as 15-5PH (vacuum arc remelted). The grade of shaft material used is chosen for its ductility and exceptional strength at low temperatures. Consideration must also be given to the electrical properties of the shaft, since the motor rotor is installed directly on the shaft common to the pump and motor. Wear rings and bushings are normally made from bronze, which has proven to provide excellent thermal characteristics at low temperatures. Other bushing materials are also in use using graphite and sintered bronze materials.

The rotating assembly is supported on rolling element bearings. The bearings are similar to standard deep groove bearings but the carrier has been modified to use a graphite resin material that provides excellent thermal characteristics, low friction, and some lubrication capability. The bearings are made from 440C steel, which has shown good corrosion resistance and low temperature stability.

The electric motor for the submerged electric motor pump is quite simple. It is basically a random wound motor that is installed directly into the pump in its own housing. The pumped liquid cools the motor and bearings. The common shaft and bearings allow the pump to be in alignment when assembled at the factory, which allows for fast and easy installation at site.

In some cryogenic liquid applications, a similar, canned motor type pump has been used. The canned motor type pump uses a lining or metal enclosure around the motor to prevent contact with the liquid, and therefore can be used even in liquids that are conductive or would otherwise be harmful to the motor. Since the design described in this paper is used in nonconductive liquids, the metal canning is not required. The elimination of the motor can allows larger motors to be used, as there are no eddy current losses to be concerned with. In addition, in a cryogenic environment, the thin metal can or lining can deform and become damaged due to contrasting thermal coefficient rates as the motor warms up but the surrounding liquid remains cold.

The electric motor itself is made from traditional silicon steel laminated plates pressed together. For the stator, they are welded on the outside, with the windings installed in either a random or form-wound technique, depending on the voltage. The wire used is normally a glass-insulated copper wire. The stator is impregnated

with an epoxy resin that is selected for its ability to remain somewhat flexible even at cryogenic temperatures. The impregnation of the stator is done in a vacuum chamber to remove all the trapped air. The rotor is also made up of laminated plates, which are pressed together and then the aluminum rotor bars are either cast or inserted into the rotor slots. The assembled rotor is then heated and placed directly on the pump shaft by interference fit. Motor capacities range from 3.7 kW (5 hp) to over 1492 kW (2000 hp) with voltages of 200 to 6600 VAC.

Due to the unique design of cryogenic submerged electric motor pumps and their operating temperatures, the verification of their performance is a challenging task. Testing the pumps in water is impossible due to the motor construction and electrical wiring and the motor is not sized for water specific gravity, which is much higher than the cryogenic liquids. Testing in the actual liquefied gases is the only real solution. Testing should be conducted in butane, propane, LNG, or liquid nitrogen to verify performance as close as possible to actual field conditions. Testing methods should follow API 610 (1995) requirements, with the exception of the fluid being pumped. A typical closed-loop test schematic is shown in Figure 8. The advantages of testing in the liquefied gas close to design conditions are:

- Verify motor performance and starting ability in the cryogenic liquid.
- All components will be stressed at actual operating temperatures with verification that no ill effects due to differential shrinkage will occur.
- Verify mechanical alignment and freedom from rubs and binding due to cold temperatures.
- Verify pump performance characteristics using the cold boiling liquid, which is extremely important for NPSH testing.
- Verify no internal leakage due to deformation or differential shrinkage.

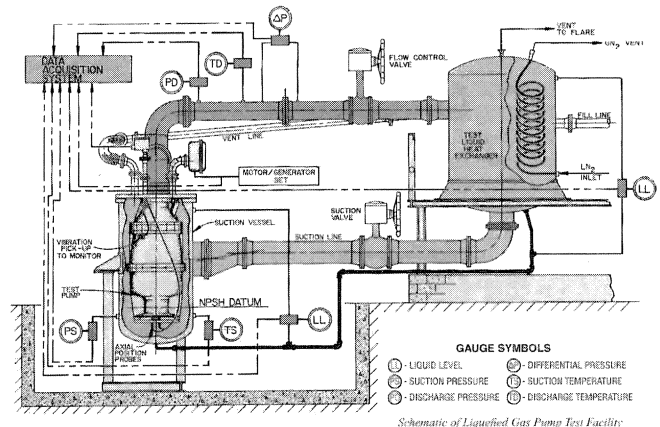


Figure 8. Closed Loop Cryogenic Pump Test Arrangement.

COOL-DOWN AND OPERATION

The cool-down of a cryogenic submerged pump is a critical operation. Because of the construction, using materials with very different thermal coefficients, a rapid cool-down can overstress the materials, resulting in yielding and premature failure. Due to this, the cool-down must be done in a very controlled manner per the manufacturer's instructions.

The operation of a cryogenic submerged pump is much the same as any conventional centrifugal pump. The differences lie mostly in the fact that the liquid is normally pumped close to its boiling point.

When a cryogenic liquid is handled close to its boiling point, any decrease in pressure can cause cavitation in the pump. Cavitation

noise with a cryogenic liquid is much the same as in water, which is a rumbling or crackling noise, associated with higher vibration. When cavitation occurs, since the pump is now pumping partial or total vapor, a fluctuation or reduction in motor amperage and discharge pressure is also experienced.

Due to the critical nature of maintaining vapor-free liquid, operation of a submerged cryogenic pump should be kept within the guidelines specified by the manufacturer. In addition, various protective devices should be installed to prevent operation when certain parameters are exceeded. These protective devices normally consist of the following:

- *Low amperage trip*—Low amperage usually indicates cavitation or lack of liquid.
- *High amperage trip*—High amperage indicates operation above normal, or an internal mechanical problem.
- *Low suction pressure trip*—This item will protect the pump against cavitation or loss of suction liquid.
- *Low flow trip*—Protects against cavitation as well as operation below the recommended minimum flow rate
- *Low discharge pressure trip*—Protects against cavitation as well as pressure loss due to internal wear and mechanical damage

Many pumps are now also supplied with submersible vibration detection systems. These systems are normally in the form of an accelerometer mounted directly to the pump housings, with instrument cable going up and out of the vessel or tank in much the same way as the main power cables. The instrument cable then goes to a monitor in an instrument room, and is also usually linked to the main control room computer system. These systems can provide a vibration level for normal operation, and can provide alarms if vibration levels exceed the alert set point. The vibration system can also be a valuable tool for troubleshooting, by allowing spectrum analysis of the vibration, which can be used to identify faults or impending failure.

As with any rotating machine, the cryogenic submerged pump can be monitored using traditional trending techniques. The values normally used for trend monitoring are flow, discharge pressure, amperage, and vibration (if available). Any abrupt change in these values may indicate a mechanical problem or wear and should be investigated.

MAINTENANCE

Throughout the years, and particularly with more modern calculation means, the cryogenic submerged pump has proved to be a very reliable machine. Since the pump is normally installed in a clean, noncorrosive environment, and is not exposed to the atmosphere, extremely long running hours are possible. In fact, maintenance is normally not required unless some type of problem or deterioration in performance is encountered.

When maintenance is required, however, it is not difficult due to the simplicity of the design. Normally, all that is required is replacement of worn components such as the ball bearings, bushings, and wear rings.

Traditionally, land-based units are only removed for maintenance if a problem or normal wear takes place, and shipboard units are removed for maintenance when the ship pulls in for dry-dock service. In this case, usually one half of the pumps are removed during each dry-dock, which is about every two to two and one-half years.

SYSTEM DESIGN CONSIDERATIONS

When a system designer or user has decided to use a cryogenic submerged motor pump in his system, some very important aspects need to be considered.

As mentioned previously, in most cases, cryogenic liquids are handled at or near their boiling point. Therefore, the system

designer needs to be very careful to ensure pressure drops in the system do not create a situation where boiling or partial vaporization occur in the suction. Although the suction vessel of a vessel-mounted type pump can adequately act as a phase separator and much of the vapor goes out through a vent, this is usually designed only to remove the vapor generated by the pump itself. If the liquid entering the suction vessel already contains a significant amount of heat or vapor or the liquid is near its boiling point, significant flashing may occur in the vessel, causing cavitation.

This becomes extremely important in systems such as LNG send-out, where boil-off gas is sometimes reintroduced into a phase separator prior to entering the pumps. The phase separator or recondenser must be designed and sized carefully to avoid cavitation in high-pressure send-out pumps.

In order to ensure that any vapor created is allowed to escape, the vent system also needs to be carefully designed. The vent piping should be adequate in size to allow for the inefficiencies of the pump, and be constantly rising and unobstructed to its discharge point. The destination of the vent is also important, to ensure adequate pressure drop exists so that flow of the vent gas is sufficient. It is surprising how many cryogenic pump installations have been built that do not adequately address these basic needs.

Another important system consideration is cleanliness of the liquid. Due to the low viscosity of a cryogenic liquid, very close clearances are used in the pump bushings and wear rings. These close clearances make a cryogenic pump somewhat susceptible to particulate damage. Therefore, the selection of materials used in a system is important, as well as the use of low-point piping traps, filters, etc., should be used when foreign particles such as rust, sand, or dirt are expected.

SELECTION OF A CRYOGENIC SUBMERGED MOTOR PUMP

The first, most important criterion to be considered when selecting a cryogenic submerged pump is the liquid being handled. In order to first use this type of pump, the liquid must be nonconductive, free of water or other elements that may cause particulate damage when frozen, and be compatible with the materials used in the pump. The manufacturer should be consulted when any questions exist concerning the compatibility of a cryogenic submerged electric motor pump for an application.

Generally, a cryogenic submerged electric motor pump is selected in the same manner as other centrifugal pumps. The basic requirements that should be given to the manufacturer for selection are as follows:

- Flow
- Suction pressure and temperature
- Discharge pressure
- NPSH available
- Liquid properties, specific gravity
- Duty cycle
- Power supply voltage and frequency

Normally, support from the manufacturer as well as the engineering companies related to the project should be considered. Many companies that have extensive experience with cryogenic submerged pumps are willing to share their experiences and advice.

When choosing a supplier, the cost of the product as well as the experience of the supplier is extremely important. Since the design of a cryogenic pump can be critical to its reliability, choosing a supplier with extensive experience and field-proven equipment is an important consideration. Not only the cost of the product, but also the long-range costs of the pump efficiency, maintenance, maintenance support, and thus the total cost over the life of the equipment should be considered.

CONCLUSION

The development and extensive use of the cryogenic submerged electric motor pump prove that it is ideally suited for liquefied gas applications. The features of the design are also well suited for trouble-free operation and reduced maintenance. As long as the system designer or engineer making the selection considers the aspects required for successful operation for this centrifugal pump type, the cryogenic submerged electric motor pump can be used for a wide range of liquefied gas applications.

REFERENCES

API Standard 610, 1995, "Centrifugal Pumps for Petroleum, Heavy Duty Chemical and Gas Industry Services," Eighth Edition, American Petroleum Institute, Washington, D.C.

BIBLIOGRAPHY

- Weisser, G. L., January 1994, "Modern Submersible Pumps for Cryogenic Liquids," *World Pumps*.
- Hylton, E. H., 2000, "State of the Art Submerged Cryogenic Motor Pump and Turbine Generators," Proceedings of Gastech 2000 Conference, Houston, Texas.
- Cullen, D., Rush, S., and Madison, J., September 2000, "Radial and Axial Diffusers for Submerged Electric Motor-Driven Pumps," *World Pumps*.
- Rush, S., 1994, "Effects of Unbalanced Magnetic Pull in Cryogenic Submerged Electric Motor Pumps," Proceedings of the Vibration in Fluid Machinery Conference, ImechE.

