Magnetically Coupled Submerged Cryogenic Pumps and Expanders for Ammonia Applications

Liquefied Ammonia, or Liquid NH3, is (like LNG or liquefied natural gas) a cryogenic fluid and production and transportation require machinery that is similar in design to that used in LNG. Rotating machinery is an important part of this cryogenic fluid technology, in particular if these fluids are also flammable like LNG and corrosive like Ammonia. This paper presents a description of the design and application of submerged magnetic coupling rotating machinery for Liquid NH3 and a discussion on the safety aspects and details of the design.

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Introduction

Ammonia is one of the most widely produced chemicals in the world and is mainly made by synthesizing natural gas. It is utilized in multiple applications, for fertilizers, refrigerants, explosives and waste water treatment plants. It is also employed in the industrial production of rubber, leather and paper. Ammonia, like hydrogen, is also a carbon free liquid fuel.

Liquefied Ammonia (Liquid NH3) is a cryogenic fluid like Liquefied Natural Gas (LNG). Production and transportation require technologies that are analogous to those used in the LNG industry. Rotating machinery is an important part of this cryogenic fluid technology, in particular if the fluids are also flammable and corrosive like ammonia.

This paper will discuss designs and applications of submerged magnetic coupling rotating machinery for Liquid NH3 applications with a discussion on the safety aspects.

Magnetic Coupling Pumps

Ammonia is a particularly difficult liquid to handle, as it is very hazardous to personnel if the gas is present and can cause severe asphyxiation, even at very low concentrations. In addition, ammonia is also very flammable, highly corrosive to copper and copper alloys, and has a huge affinity for water which can make it highly conductive unless it is in its purest form.

To meet the challenge of pumping Liquid NH3, Ebara International Corporation (EIC) has developed a submersible, magnetic coupling design which is in use today in several locations (Figure 1). This design uses a sealed stainless steel casing to house the motor, which has inert nitrogen gas fed into the casing from the outside of the pump vessel or tank to keep the motor section dry and free of ammonia (Figure 2). The nitrogen pressure can be maintained to prevent ammonia from entering the casing and also to provide the proper differential pressure across the magnetic coupling membrane.

Figure 1: Installation of EIC In-Tank Ammonia Pump

The key feature of the design is safety. The pump has no penetrations through the vessel or outer casing with a shaft seal, so there is no possibility of leakage into the surrounding atmosphere. In addition, since the motor is located within the tank or vessel along with the pump hydraulic section, there is no need for an explosion-proof housing around the motor since the interior of the tanks, under operating conditions, do not have oxygen present.

These pumps can be installed in a suction vessel to act as an in-line design that can be used in almost any location where it is necessary to transfer liquid or boost pressures, including from tanks where a few specifications still specify bottom or side connections. The liquefied gas industry almost universally recognizes the enhanced safety of having no penetrations below the liquid level, where pumps are installed in storage tanks in a pump column similar to a submersible deep well design to transfer liquid from the storage tank to another location such as a ship or other process area.

For larger storage tanks, the retractable, or in-tank, type of magnetic coupling pump is an excellent choice for the application as it is installed through a column from the top of the tank. In many ammonia tank applications, where the liquid is stored at near atmospheric conditions, an external shaft seal type pump is used, which requires a side or bottom penetration from the storage tank. The penetrations, with valves in the piping, are potential leakage areas and the pump type used would have the same issues as noted above with the external motor and shaft seals.

For the electrical portion of the Ebara design, the power cables from the motor are enclosed in a flexible conduit/hose arrangement that is seal welded on both ends. This conduit, which is connected from the head plate at the top of the tank to the motor casing at the bottom, allows nitrogen gas to be applied into the hose and casing to keep those spaces inert and free from moisture.

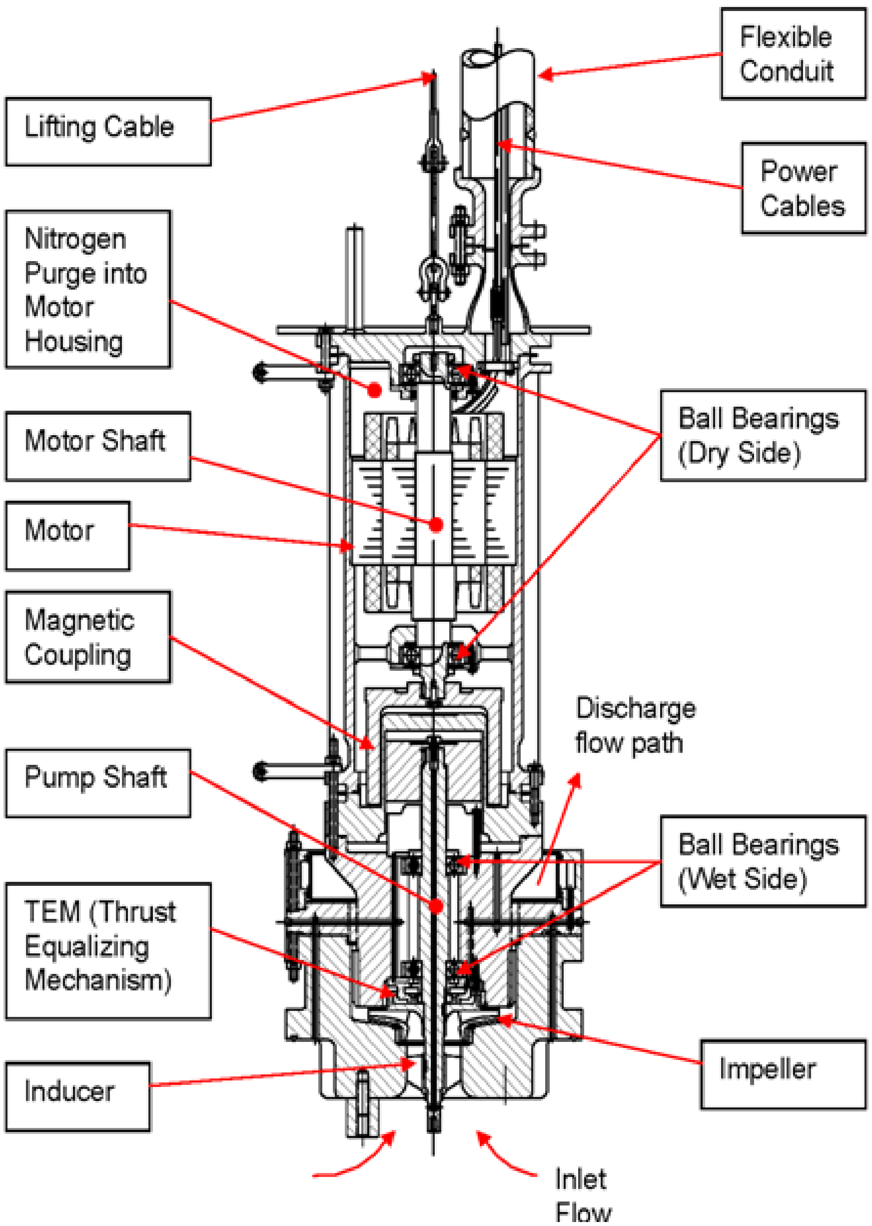


Figure 2: EIC Ammonia Pump Design with Magnetic Coupling

This space can also be monitored to determine if any leakage is present, and if such an event happens, the pump electrical system can be shut down immediately for safety purposes.

At the top of the electrical system, to enable the power cables to exit the tank, a dual seal penetration is used, which is the same design used for pumps and liquid expanders used in LPG, LNG, ethylene and other liquefied gas applications. The design meets all of the more common codes such as NFPA 59 and 59A, and meets the requirements of NFPA 70, National Electrical Code, for equipment used in Class 1, Division 2, Group C/D atmospheres. The equipment also meets applicable IEC codes for Class I, Zone 1 or 2 hazardous areas. This system has been in regular use in thousands of applications and has proven to be extremely safe and reliable.

For the pump design itself, many features from EIC's standard submerged motor pumps are used. The hydraulic end of the pump carries the impeller(s) and inducer as well as the wet end coupling, and the bearings are product lubricated (Fig. 2). This is a stiff shaft design which uses low mass rotating components made from aluminum to ensure minimal radial loads and low vibration, thereby extending bearing life. The motor section, or dry end, uses typical shielded grease filled bearings with the magnetic coupling attached at the lower end.

Another key feature in the design is the use of EIC's Thrust Equalizing Mechanism (TEM), which is a built-in axial balancing system that eliminates axial thrust loads on the bearings at all flow rates using the pumped fluid. When using the pumped product, which in this case is a liquefied gas, for lubrication, it is imperative that the axial thrust loads are totally balanced to prevent vaporization of the fluid in the bearings to ensure reliability. This system has been used in many thousands of liquefied gas pumps all over the world with very high reliability.

EIC's pump design also uses an inducer, or axial flow impeller, in the inlet to provide very good NPSHR characteristics (Figure 2). The inducer is designed to enable operation of the pumps in very low liquid level situations and is perfectly suited for storage tanks on land and in marine applications.

The current design was developed in the mid 1990's and eleven units are now installed and operating in Taiwan and mainland China with the most recent units just installed in a plant near Shanghai. The overall design, with the electric motor, magnetic coupling and TEM is also patented (US Patent number 6,213,736 B1).

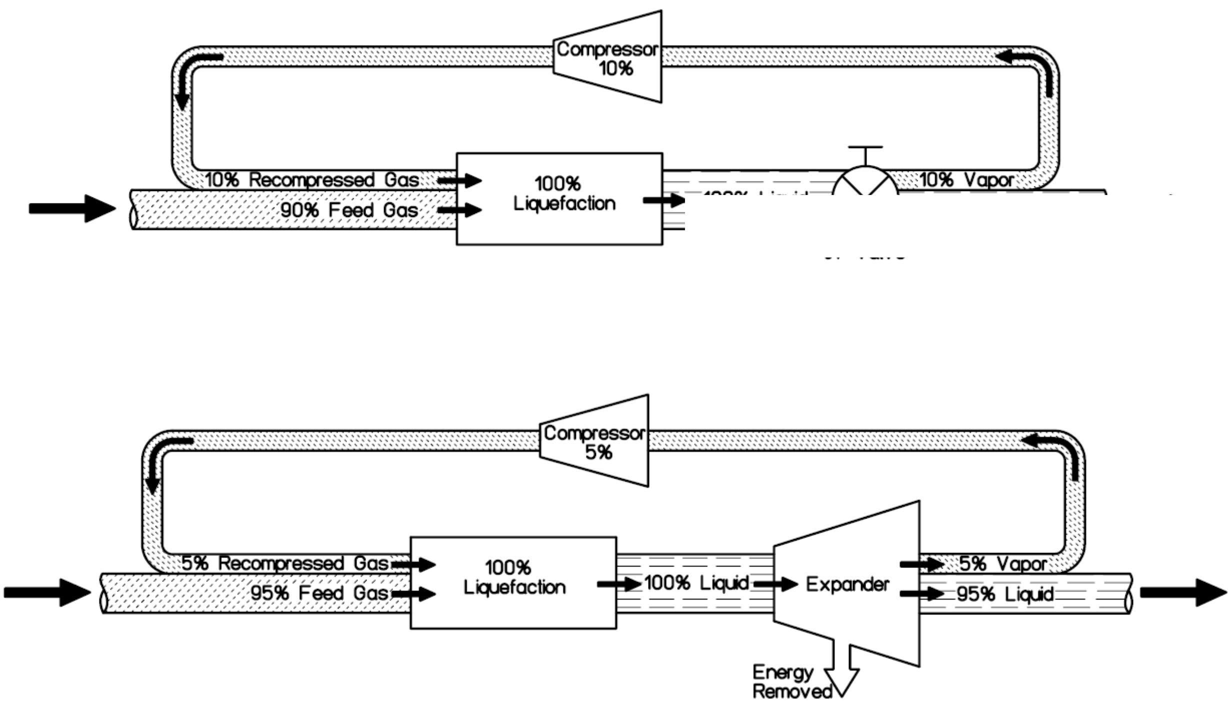
Magnetic Coupling Liquid Expanders

As the magnetic coupling pump for ammonia service has now been in operation for a number of years, it has become obvious that the design can be adapted for other rotating machine applications. In the manufacture of LIQUID NH3, the processes used are very similar to those used to liquefy natural gas or other liquefied gases which are at cryogenic temperatures at atmospheric pressure.

In the cryogenic liquefaction process, the process gas must be cooled, compressed, and expanded in order to liquefy the gas for efficient and compact transportation and storage. As part of the process, the liquid pressure must be dropped to allow the liquid to go into another stage of compression, or for transfer into low pressure storage. Typically, the pressure drop is accomplished by expanding the compressed fluid in an isenthalpic process across a Joule-Thomson (JT) valve. In the JT pressure reduction, the enthalpy of the liquid does not change and depending on the inlet and outlet pressures and the temperature of the fluid may increase or decrease. Pressure drop across a JT valve also creates high turbulent friction losses, wasting energy through frictional heating of the fluid reducing the amount of liquefied ammonia. Substitution of liquid ammonia expanders in place of liquid JT valves will increase the amount of liquefied ammonia and improve the overall system efficiency while recovering electric power.

In order to provide a much more efficient drop in pressure, as an isentropic expansion, a rotating machine such as an expander can be used in place of a JT valve. In LNG liquefaction plants, EIC developed an expansion turbine several years ago, and that type of expander is now used in many liquefaction systems today. These machines are now well proven and are known to increase the overall process efficiency by as much as 4% to 7%. Figure 3 is a simplified schematic comparing the benefits of installing a liquid expander in the place of a JT valve in an existing liquefaction plant. The key difference between a JT valve (Fig. 3a) and an expander (Fig. 3b) is that the expander reduces the vapor resulting from the liquid expansion. This reduction in vapor output decreases the required re-compression which in turn increases the percentage of both the feed gas input and the process output, all while recovering energy. As an additional benefit, replacing a JT valve with an expander does not require other plant size or capacity changes.

The design of the machine uses many of the same features found in the submerged motor cryogenic pumps, but uses nozzle rings to direct the flow into the rotating expander runners, which are connected to a generator on a



(a)

(b)

Figure 3: Joule-Thomson Valve and Expander Comparison Schematic

common shaft. The torque created by the generator is then used to extract energy from the fluid stream, thereby creating the thermodynamic efficiency that essentially produces more liquid versus vapor in the expansion process. The EIC design uses fixed vane nozzle rings directing the flow into Francis type radial inflow runners which are designed to extract the maximum amount of torque from the fluid as possible. The machine is also often enhanced using variable speed technology where the generator speed is controlled using a Variable Speed Constant Frequency (VSCF) controller, thereby providing flexibility in the operating range to optimize the efficiency of the process system.

For ammonia liquefaction, EIC is developing an expander that uses the same hydraulic and generator technology as the machines used for LNG liquefaction coupled with the technology of EIC ammonia pumps to produce a unique machine for this application using proven technology. By marrying these technologies together, the typical ammonia plant can now benefit in a much more efficient process which will lead to an increase in production while reducing required power for compression. In fact, by replacing the traditional Joule-Thomson type expansion system in an existing plant with the expanders, the same volumetric flow can be achieved with a 5% reduction in compression and 5% reduction in overall liquefaction energy.

Improving the Ammonia Liquefaction Train Using Two-Phase Expanders

The history of liquefaction starts with the first continuous process invented in 1895 to liquefy air which essentially compresses and cools and then expands the gas to a lower temperature until the gas condenses. Ever since then, major improvements have been made to the process beginning with the gas expander. Another leap in the technology came with the replacement of the JT valves in the liquid expansion step with liquid expanders. It follows that the improvement in the liquefaction process is with the integration of two-phase expanders to replace the JT valves used for two-phase expansion.

EIC currently has several two-phase LNG expanders in operation and is on the forefront of two-phase expansion technology. Figure 4 shows the current EIC hydraulic design for LNG two-phase expanders which can easily be adapted to operate within the magnetic coupling design for ammonia expansion. Again by combining already known and proven technology in the LNG and ammonia industries, a two-phase ammonia expander can be developed to replace the two-phase JT valve in the liquefaction process.

Figure 4: Two-Phase Hydraulics

The two-phase expander recovers most of the available energy from the LNG stream while further cooling the liquid and thus reducing boil off downstream and increasing liquid production. By replacing the two-phase JT valve with a two-phase ammonia expander, the enthalpy of the liquefied ammonia is significantly reduced and the frictional heating in the process is kept to a minimum. More importantly, the two-phase expander eliminates the need for JT valves in the liquefaction process.

Summary

For normal ammonia pump applications, Ebara International Corporation has developed a unique, proven design that enhances safety in a very difficult environment. The design not only improves safety but in doing so, also increases reliability by removing troublesome components that are prone to leakage.

Furthermore, by marrying proven ammonia pump technology with proven liquid and two-phase expander technology, a new expander with a magnetic coupling can be installed in the ammonia liquefaction process to increase plant efficiency while keeping the same inherent safety philosophy intact. Additionally, the application of two-phase expander technology in ammonia liquefaction will increase liquid production while recovering electrical power and thus further improve overall plant efficiency.