RECIPROCATING CRYOGENIC PUMPS AND PUMP INSTALLATIONS FOR HYDROGEN AND LIQUEFIED NATURAL GAS

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Prepared by

As part of a programme of harmonisation of industry standards, the European Industrial Gases Association, (EIGA) has published EIGA Doc 243, *Reciprocating Cryogenic Pumps and Pump Installations for Hydrogen and Liquified Natural Gas*, jointly produced by members of the International Harmonisation Council and originally published by the Compressed Gas Association as CGA P-96.23, *Reciprocating Cryogenic Pumps and Pump Installations for Hydrogen and Liquified Natural Gas*.

This publication is intended as an international harmonised standard for the worldwide use and application of all members of the Asia Industrial Gases Association (AIGA), Compressed Gas Association (CGA), European Industrial Gases Association (EIGA), and Japan Industrial and Medical Gases Association (JIMGA). Each association's technical content is identical, except for regional regulatory requirements and minor changes in formatting and spelling.

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1 Introduction

Reciprocating cryogenic pumps are key components in hydrogen and liquefied natural gas (LNG) service. To ensure that pumps operate both safely and reliably in liquefied flammable gas service, it is important that reciprocating pumps are correctly designed, installed, operated, and maintained as required for the duty.

Pumping these fluids is accompanied by some degree of hazard. The hazards include liquid under pressure, cryogenic temperatures, volume and pressure increases due to vaporization, and flammability of the vapor.

This publication contains a summary of industrial practices and is based on the combined knowledge, experiences, and practices of industrial gas and equipment suppliers to manage these hazards.

2 Scope and purpose

This publication covers cryogenic reciprocating pumps and pump installations for hydrogen and LNG service.

The information contained in this publication only applies to new installations designed after the publication of this document and not to existing installations. However, the information contained in this publication may benefit existing installations or those in the project phase.

This publication does not cover:

- Cryogenic reciprocating pumps and installations for liquid oxygen, argon, and nitrogen, which are covered in EIGA Doc 159, *Reciprocating Cryogenic Pumps and Pump Installations for Oxygen, Argon, and Nitrogen* [1];[1]
- Centrifugal liquid oxygen pumps, which are covered in EIGA Doc 148, *Stationary, Electric-Motor-Driven, Centrifugal Liquid Oxygen Pumps* [2]; and
- Carbon dioxide pumps, which are covered in CGA G-6.3, *Carbon Dioxide Cylinder Filling and Handling Procedures* and EIGA Doc 83, *Recommendations for Filling of Cylinders and Bundles with Carbon Dioxide* [3, 4].

3 Definitions

3.1 Publication terminology

3.1.1 Shall

Indicates that the procedure is mandatory. It is used wherever the criterion for conformance to specific recommendations allows no deviation.

3.1.2 Should

Indicates that the procedure is recommended.

3.1.3 May

Indicates that the procedure is optional.

[1] References are shown by bracketed numbers and are listed in order of appearance in the reference section.

3.1.4 Will

Is used only to indicate the future, not a degree of requirement.

3.1.5 Can

Indicates a possibility or ability.

3.2 Technical definitions

3.2.1 Cavitation

Phenomenon that occurs when the pressure of a liquid drops to less than the vapor pressure of the liquid at a certain temperature. At this point, liquid vaporizes, thereby creating vapor bubble(s). These bubbles can cause a pump to lose prime or suffer heavy vibration and damage.

3.2.2 Cold end

Pump assembly, typically cylindrical, through which the cryogenic liquid passes and is elevated in pressure.

3.2.3 Cryogenic reciprocating pump

Motor (single, two, or variable speed) belt drive, gear drive, hydraulic drive, or direct couple assembly, warm end (crank drive), and one or more cold end.

3.2.4 Distance piece

Extended spacer or carrier frame between the cold end and the warm end.

NOTE—A distance piece is used to provide a thermal barrier and a physical separation between the process and the drive mechanism.

3.2.5 Classified area

Location in which a combustible gas is or can be present in the atmosphere in sufficient concentrations to produce an ignitable mixture.

3.2.6 Loss of prime

Loss of liquid flow to and/or through the pump.

3.2.7 Net positive suction head available (NPSHa)

Margin of difference (measured in height) between the actual pressure of a liquid flowing into a pump and the vapor pressure of the liquid.

3.2.8 Net positive suction head required (NPSHr)

Pressure or energy required at the pump to overcome frictional losses from the inlet into the cylinder without causing vaporization.

NOTE—NPSHr is determined by the pump manufacturer.

3.2.9 Purge gas

Ambient temperature, dry (dew point of –40 °C (-40 °F) or less), oil-free, particle-free, and carbon dioxide-free (less than 3 ppm) nitrogen or argon used to sweep away or prevent concentrated oxygen or moisture laden air.

3.2.10 Warm end

Mechanism such as a crank case box that drives the piston in the cold end.

4 Description of a reciprocating cryogenic pump and pump installation and components

A general arrangement of a cryogenic pump installation typically consists of a vacuum-insulated cryogenic tank, reciprocating pump, a vaporizer, and interconnecting and delivery piping. An example of a general arrangement of a typical cryogenic pump installation is shown in Figure 1. Cryogenic pumping systems shall be designed to ensure that required controls and safety elements are used in accordance with the application of the system.

Typical applications include fueling stations for vehicles and filling of compressed gas cylinders. However, there are other applications where high pressure gas or cryogenic fluid is required.

In most cases, the pump is supplied with liquid from a vacuum-insulated cryogenic tank consisting of an inner vessel and an outer jacket. There are two main types of vacuum-insulated cryogenic tanks used in cryogenic reciprocating pump installations. One type is a thermosiphon tank. The other is a conventional use tank. Both tanks are described in more detail in 5.1.

The reciprocating pump increases the pressure of the cryogenic fluid to the required pressure of operation, as described in 5.2.

If the product is required as a gas, then the product passes through a vaporizer to convert it from liquid to the gaseous phase. Vaporizers can be ambient relying on surrounding air to vaporize the product or there may be an external heat source such as hot water, steam, electricity, or hot air.

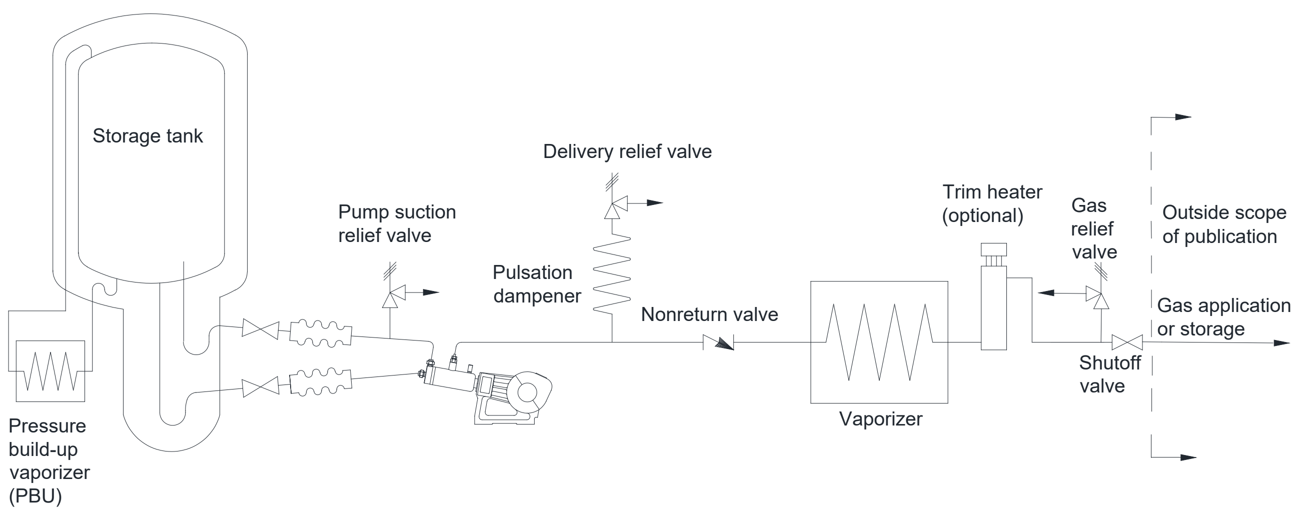

Figure 1—Example of a general arrangement of a typical cryogenic pump installation

5 Description of individual components

5.1 Tanks

Installations can use a thermosiphon tank or a conventional tank with dedicated pump feed and return piping. A simplified piping arrangement for a thermosiphon tank and a conventional tank are described in 5.1.1 and 5.1.2.

Tanks and related piping shall be designed to ensure that required controls and safety elements are used in accordance with the application of the system.

5.1.1 Thermosiphon tank

An example of a simplified thermosiphon tank piping arrangement is shown in Figure 2.

The pump feed and return piping ensures good suction conditions to the pump when running and during standby. The rate of tank pressure rise and therefore vent losses are reduced.

The thermosiphon tank design incorporates both the suction and return pipes in a vacuum-insulated jacket extension that descends from below the tank to a point almost level with the ground.

The pump suction pipe descends from the center of the inner vessel to a low point within the vacuum-insulated jacket extension. This pipe then rises and exits the vacuum jacket, continually rising towards the pump. A liquid return from the pump suction rises back towards the vacuum-insulated jacket extension. After penetrating the vacuum jacket, it is then connected to the inner vessel bottom head. The return connection is usually made closer to the inner vessel outer diameter than the suction feed. The return pipe is usually extended internally up from the bottom head to ensure that the warmer return liquid rises away from the lower pump suction feed nozzle.

Shallow gas traps are included on both feed and return pipes within the vacuum-insulated jacket extension to stop external pipes from retaining cryogen and thereby icing when a pump is isolated.

Heat gained in the external pump piping reduces the cryogenic liquid density sufficiently to generate a thermosiphon circulation of liquid from suction to return piping even when the pump is not running.

For effective operation, designers should ensure that a sufficient height difference exists between suction and return tank connections, ensure that the pipe slopes are preserved, and keep the depth of internal gas traps to a minimum.

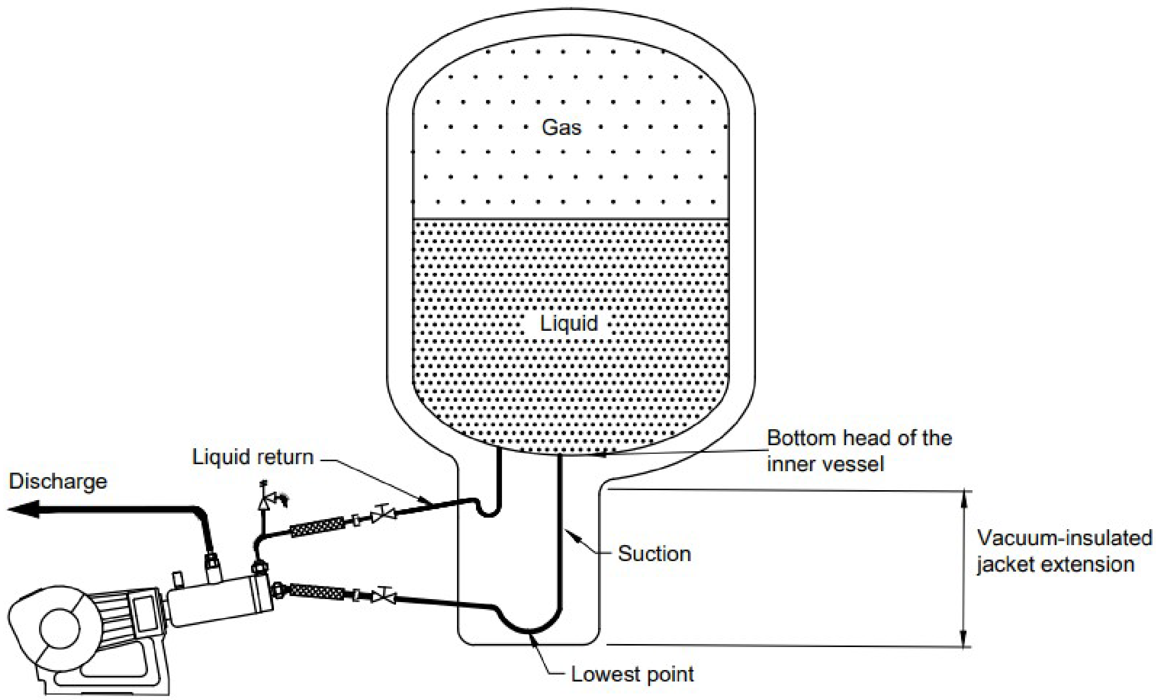

Figure 2—Example of a simplified thermosiphon tank piping arrangement

5.1.2 Conventional tank

An example of a simplified conventional tank piping arrangement is shown in Figure 3.

The pump suction feed is from a pipe dedicated for this purpose and is typically vacuum-jacketed piping for hydrogen service. A suction vapor return line allows vaporized liquid to flow to the top head of the inner vessel.

Depending on the actual pipe routing between the inner and outer vessel, the disadvantage of this liquid feed-vapor return arrangement for tanks with nonvacuum insulated pump feed lines can be that once the tank level falls below a certain level, the feed to the pump effectively becomes a long single pipe containing at least one gas trap. If the pump shuts down for even a short period, the liquid in the suction piping rapidly reaches its boiling point and the pipe becomes vapor locked.

If venting is required to achieve pump priming, it shall be done in a safe manner to an appropriately designed vent circuit.

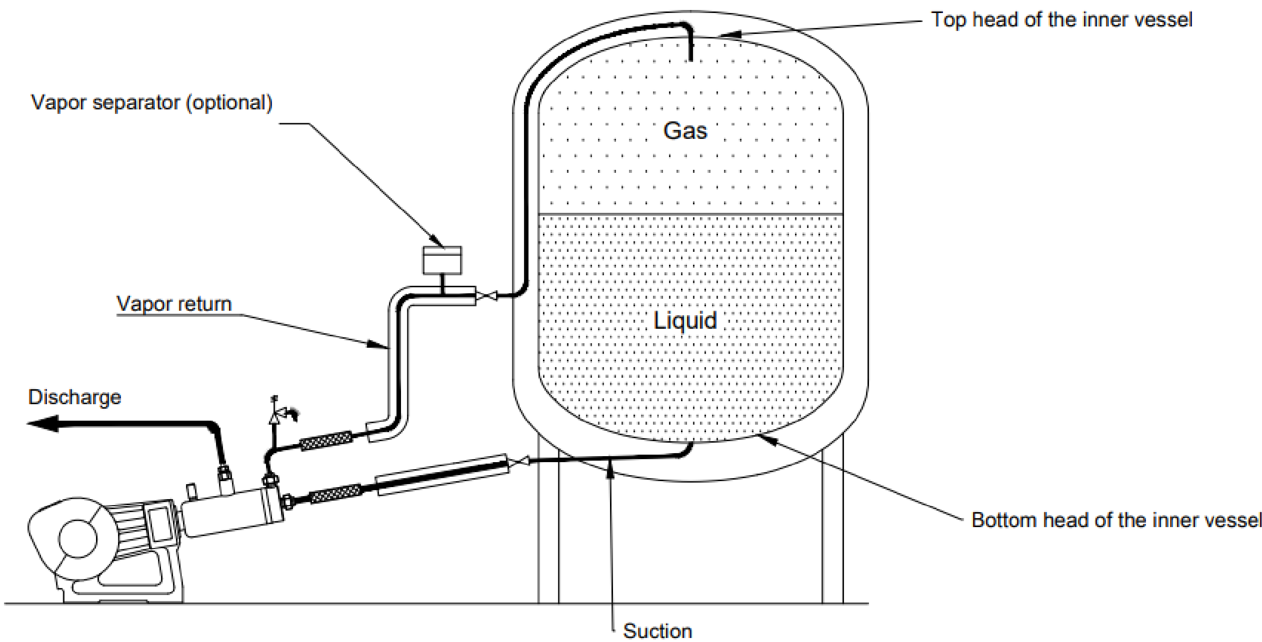

Figure 3—Example of a simplified conventional tank piping arrangement

5.2 Pump

A variety of pump configurations are in use. Typical cryogenic reciprocating pump components are shown in Figure 4 and recommended materials are covered in Section 6. Figure 5 shows a typical cold- and warm-end assembly.

A means for vapor escape for pump priming is required; typically, back to the storage tank.

The pump is usually driven by an electric motor, which shall be rated in accordance with applicable regulations (for example, NFPA 70, *National Electrical Code®*; ATEX Directive 2014/34/EU, *Equipment and Protective Systems Intended for Use in Potentially Explosive Atmospheres*) for the location in which it is installed [5, 6]. Any drive belts shall be static conducting and oil resistant.

The pump shall be installed with appropriate safety features depending on which flammable liquid is to be pumped and according to its location. Area classification shall be defined by the user and transmitted to the manufacturer so that an adequate level of protection can be provided.

The user may accept international standards for electrical and mechanical equipment that meet or exceed local codes and regulations. These standards define requirements for protection against ignition of a surrounding explosive atmosphere. Potential ignition sources include leaks, releases, hot surfaces, electromagnetic radiation, mechanically generated sparks, friction, mechanical impacts, electrical arcing, and static electric discharge.

The electrical components (for example, motor, instrumentation, heater, etc.) shall be certified by the manufacturer for use in the area classification in which it will be installed. Mechanical components and their assembly shall be subject to an ignition hazard assessment taking into account the normal functioning of the equipment as well as potential failure modes.

The user shall also specify the ambient temperature range as well as the temperature class, which is the maximum surface temperature permitted.

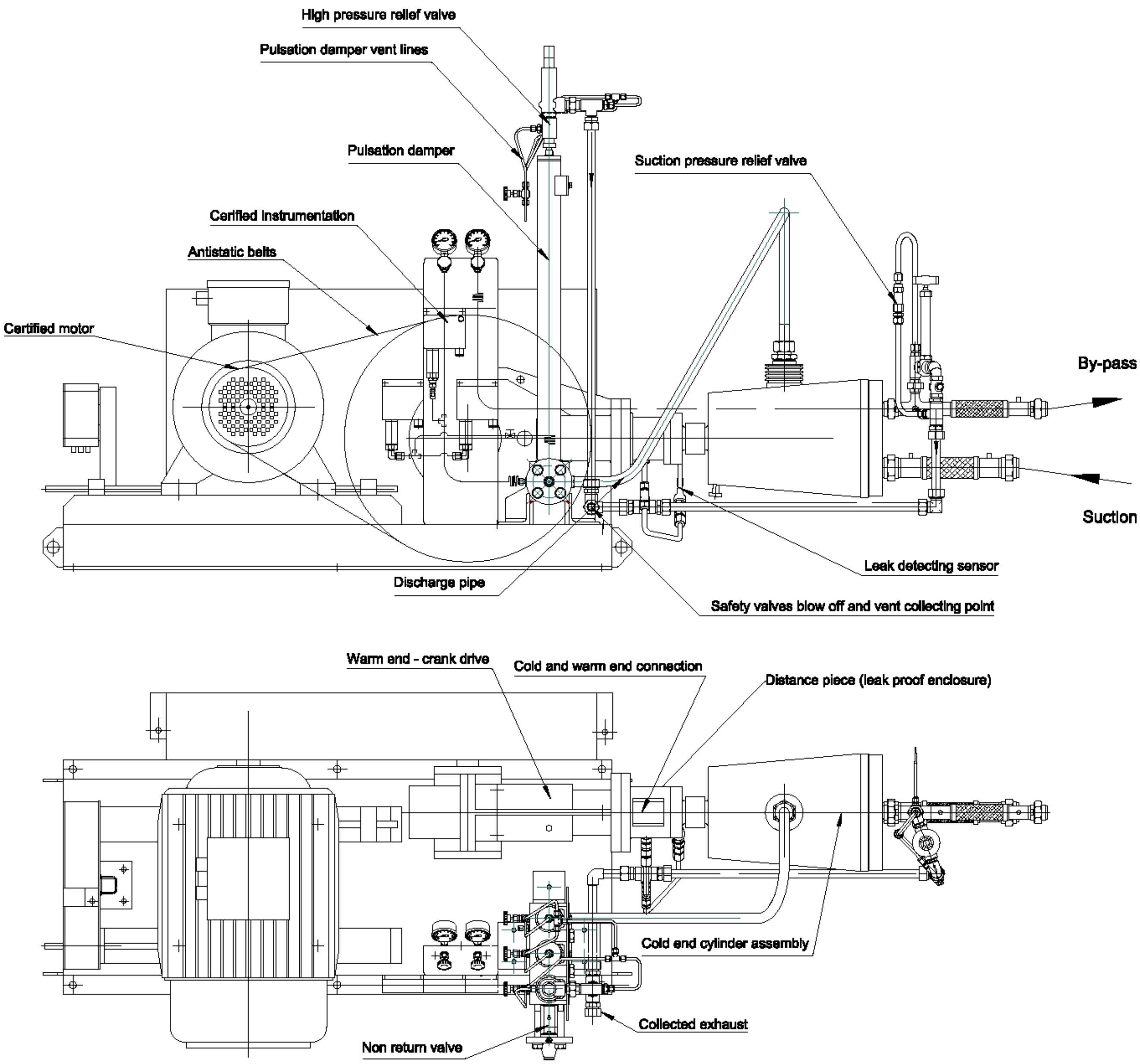

Figure 4—Example of cryogenic reciprocating pump components

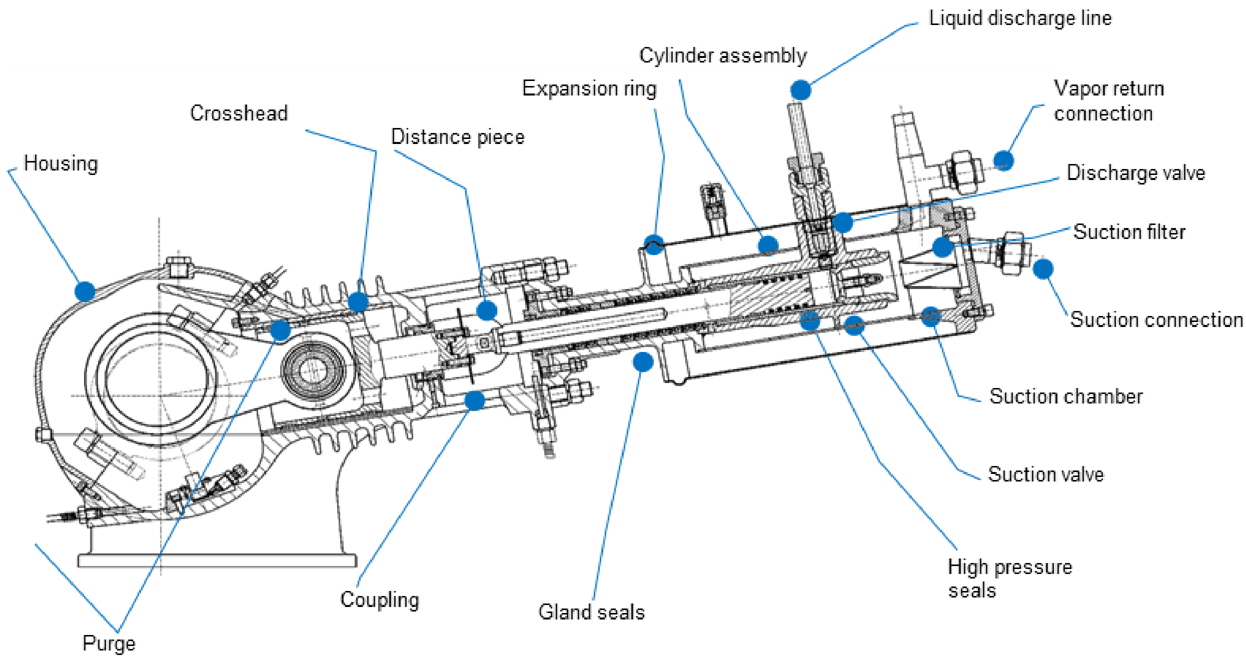

Figure 5—Example of a cold- and warm-end assembly components of a cryogenic reciprocating pump (cross section)

5.2.1 Suction filter

To prevent damage to pumps, a filter should be fitted to the suction side of the pump. Fine mesh filters (typically 150 microns or 100 mesh) are usually incorporated within the pump suction chamber. Filters should have a large surface area and be accessible for inspection or maintenance.

5.2.2 Cold-end cylinder assembly

The main components of the cold-end cylinder assembly are the piston, piston rings, cylinder, and suction and discharge valves.

Materials shall be chosen with care as addressed in Section 6.

Piston rings are often made from a plastic material including polytetrafluoroethylene (PTFE) or similar materials. As these plastics have a much larger coefficient of expansion than that of the surrounding metals, it is important to ensure that pumps are adequately cooled before operating to reduce piston ring wear and the risk of overheating.

Some cylinder assemblies are equipped with a supercharger device that brings a precompression and reduces the net positive suction head required (NPSHr) thus limiting the potential for cavitation. See Figures 6a and 6b.

An initial compression chamber transfers the liquid from the suction chamber, pushing the liquid through the suction valve, and increasing the liquid pressure in the main compression chamber to create additional subcooling.

Therefore, the NPSHr is near zero limiting the potential for cavitation. The only net positive suction head (NPSH) needed is to bring the liquid in the suction chamber through the filter.

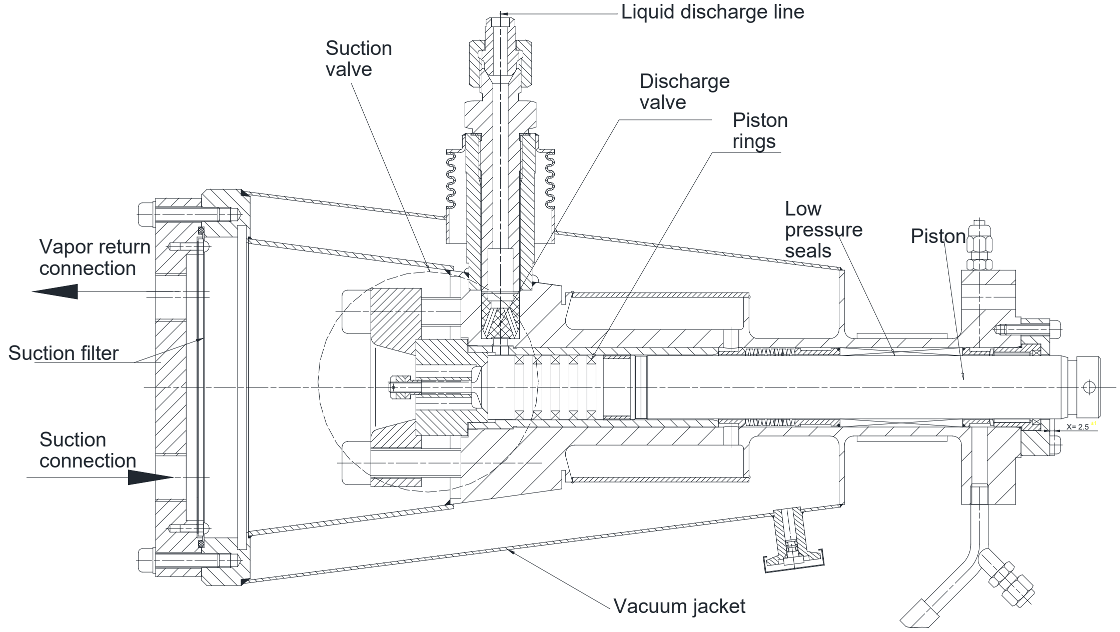

Figure 6a—Example of a cold end without a precompression chamber

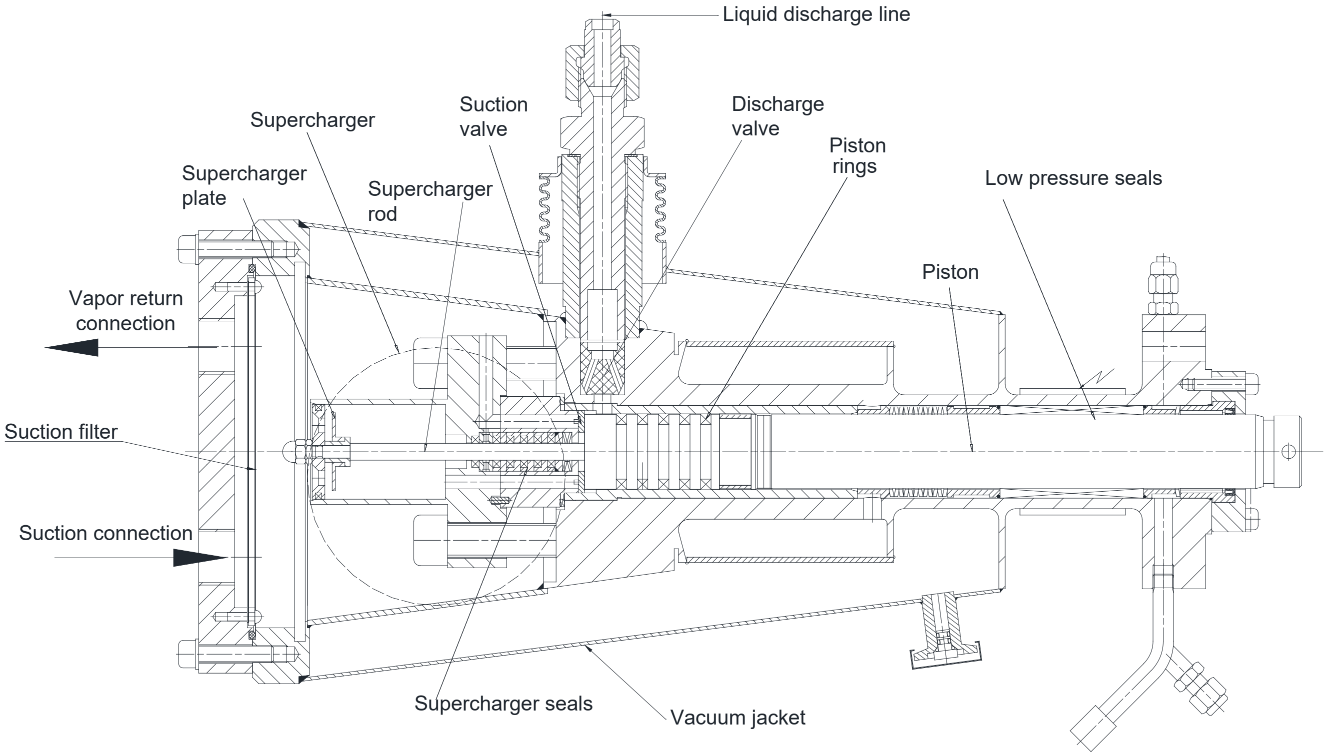

Figure 6b—Example of a cold end with a precompression chamber

5.2.3 Gland seals

Cryogenic liquid leakage to the atmosphere from the piston assembly is prevented by gland seals around the piston rod. These can be damaged by frozen moisture on the piston rod or excess play in the piston rod due to wear in the warm-end drive.

Cryogenic liquid leakage through worn gland seals has resulted in brittle failures of warm-end drives and/or fires. Avoidance and detection of such leakage is important. See Section 7.

An electrical seal heater or clamp on heater can be used to prevent over cooling of these seals. The application of a clean, warm, dry inert gas flow around the exposed piston rod can be used to extend the seal life. This gas flow shall be collected and vented to a safe location.

An electrical seal heater should only be used while the pump is in cold standby.

5.2.4 Cold- and warm-end connection

The warm and cold ends are often separated by a bolted assembly that ensures both correct alignment and transmission of forces and that any leakage of cryogenic liquid is kept away from the warm end.

Correctly tightened bolts are important to avoid fatigue-related bolt failures. This is usually achieved by the use of a torque wrench and compatible lubricant on the washers, stud, and nut threads.

As potentially explosive atmospheres may arise from any leakage towards the exterior, the distance piece shall be located in a leak-proof enclosure. This enclosure shall be vented or purged and vented to a safe location to reduce the hazard of any gland seal leak. Leak detection is important as cryogenic liquid leakage into the distance piece has resulted in brittle failures of warm-end drives and/or fires.

An enclosed distance piece, which includes the back of the gland seal, shall be equipped with purge and vent connection ports.

The purge provides inerting of the distance piece and directs potential leak flow through the vent port and the leak detection device to a safe location.

5.2.5 Warm-end drive

The piston is normally driven forwards and backwards by a crank drive and crosshead assembly. These are usually of standard design, rated for the pressure and flow rate expected for the cold end. Smaller, lower duty crank drives often have dry running crossheads and prepacked grease lubricated main rolling element bearings. Higher duty crank drives are usually oil lubricated.

The design and selection of lubricants, materials, and purge gases is extremely important to safety.

5.2.6 Electric motors

Electric motors can be fixed or variable speed and shall be selected according to the area classification in which they will be installed. The use of variable speed drives gives additional flexibility for controlling flow rates and temperatures, for example when filling small cylinders.

The electric motor shall be protected from process leaks. The motor shall be positioned so leaking or venting cryogenic fluid cannot drip onto or enter into the motor unless a risk assessment determines that the risk is mitigated to an acceptable level.

5.3 Vaporizers

High pressure ambient vaporizers used in hydrogen and LNG are typically constructed from stainless steel piping surrounded by aluminum fins.

Pressures, temperatures, and materials should be considered when designing systems for hydrogen and LNG service. 316L stainless tubing/piping is typically used in the vaporizer for hydrogen pumps and installations, and the design should consider hydrogen embrittlement. See CGA G-5.4, *Standard for Hydrogen Piping Systems at User Locations* and EIGA Doc 121, *Hydrogen Pipeline Systems* for more information on hydrogen embrittlement [7, 8].

An ambient vaporizer should be sized for the product, flow, usage cycle, and expected ambient conditions using accurate and detailed weather data for the region of operation. Ambient vaporizer sizing should be based on the winter conditions when ice loading is at its maximum.

Where there is insufficient space for an ambient vaporizer or where the water vapor cloud generated during operation may be unacceptable, vaporizers that require an external heat source can be used. These include fan assisted ambient vaporizers, water bath heated by steam, or by an indirect fired boiler. All components shall be rated for use within the classified area.

To supplement ambient vaporizers in cold climates, trim heaters with components rated for use within the classified area may be installed downstream of the ambient vaporizer. Direct electrical element contact with flammable fluid is not recommended. Only indirect heated units should be considered for trim heaters.

A review shall be conducted in accordance with EIGA Doc 133, *Cryogenic Vaporization Systems*—Prevention of Brittle Fracture of Equipment and Piping to determine if a safety system is required to prevent low temperature fluid from being delivered downstream of the vaporizer(s) in the event of vaporizer overload or failure [9].
EIGA Doc 133 gives guidance on where this is appropriate [9].

5.4 Piping and piping components

All piping shall be designed and constructed in accordance with the applicable piping code such as ASME B31-All Parts, *Pressure Piping* or EN 13480-1, *Metallic Industrial Piping – Part 1: General* [10, 11]. Piping shall be suitable for the pressure, temperature, and fluid being pumped.

The piping assembly should be designed to take into account the stresses caused by temperature cycling and vibration from a low temperature reciprocating system.

Fittings and adapters with sharp bends or changes of cross section should be avoided to keep pressure losses to a minimum.

5.5 Valves

Valves shall be suitable for the pressure, temperature, and fluid being pumped.

5.5.1 Ball valves

Ball valves are sometimes used between the tank and pump for isolation of liquid for operation, maintenance, or emergency. Ball valves are used to reduce pressure drop. Full bore ball valves should be considered.

Ball valves in cryogenic service shall either be drilled on the upstream side or designed to ensure that any liquid that could be trapped inside the ball can escape to prevent pressure buildup. A ball valve with an upstream vent hole becomes unidirectional. It can only seal against flow/higher pressure coming from the upstream/vented side. A vented ball valve shall be marked to indicate the flow direction and/or which side of the valve has the vent hole. To ensure that the pump can be fully isolated for maintenance, any pump isolation valve flow-direction arrows should point toward the pump (even if the direction is counter to the flow during normal operation). In the absence of flow arrows, the vent holes should be located to discharge away from the pump.

Ball valves in gas service should be fire rated in accordance with a standard such as API Standard 607, *Fire Test for Quarter-turn Valves Equipped with Nonmetallic Seats* or ISO 10497, *Testing of valves—Fire type-testing requirements* [12, 13].

5.5.2 Globe valves

Globe valves are commonly used for isolation between the tank and pump for operation and maintenance. They may be vacuum jacketed to minimize heat leak into the process.

Flow through a globe valve is typically from the under seat to the over seat side, however globe valves in cryogenic applications may be installed counter flow. Consideration should be given to the flow direction of the process fluid, the function of the valve, and safe operation in normal and upset conditions. For example, a valve may be installed to avoid pressure on the top works of the valve when the valve is closed.

5.5.3 Actuated valves

Use of actuators, fitted on at least the liquid feed valve(s) and gas return valves in the event of a pump failure, shall be considered to increase the protection level of the installation. When remote actuated valves are used, they shall be fail closed and close in the event of loss of pneumatic or electrical supply. The actuated valve should be located as close to the vessel as possible, downstream of the vessel isolation valve.

Actuated valves may be fitted with limit switches to confirm whether the valve is open or closed. In addition or alternatively, a low pressure switch may be fitted on the instrument gas supply to the actuator to detect loss of pressure.

Actuated valves shall be capable of remote activation from a safe location.

6 Material selection

Materials for components shall have adequate properties (for example, mechanical; low temperature; lubricating; material compatibility for the system operating temperature, pressure, and process gas; and resistance to hydrogen embrittlement). Pump and drive assembly material of construction selection shall be made to avoid ignition sources such as from the generation of sparks and/or the buildup of any electrostatic charges. The materials of construction of all major components should be clearly stated in the manufacturer’s proposal

Design criteria and guidance for material selection are included in Table 1.

Table 1—Design criteria and guidance for material selection

Design criteria	Guidance
Mechanical properties	ISO 21028-1, *Cryogenic vessels — Toughness requirements for materials at cryogenic temperature, Part 1: Temperatures below -80 degrees C*, and ISO 21010, *Cryogenic vessels — Gas/material compatibility* [14, 15]
Low temperature embrittlement	
Lubrication	
Material compatibility	
Pressure rating	
Welding	ASME B31.3, *Process Piping,* ASME B31.12, *Hydrogen Piping and Pipelines,* EN 13480-1 [16, 17, 11]

Hydrogen embrittlement	EIGA Doc 6, EIGA Doc 121 [8, 18]
Cleaning	Manufacturer shall clean the pump and any associated piping in accordance with user's requirements. For example, EIGA Doc 33, *Cleaning of Equipment for Oxygen Service* [19]. For hydrogen purity levels, see CGA G-5.3, *Commodity Specification for Hydrogen* [20].

Table 2 gives a nonexhaustive list of commonly used materials of construction for pumps and pump installations.

Materials selection for the piping and tubing shall be compatible with pressure and temperature of the fluid being handled. For example, see CGA G-19.1, *Standard for Natural Gas Supply Systems*; CGA H-3, *Standard for Cryogenic Hydrogen Storage*; G-5.4; or EIGA Doc 6 [21, 22, 7, 18].

Table 2—Typical materials of construction for reciprocating pumps

Item	Materials for Hydrogen	Materials for LNG
Cold-end cylinder assembly	316L SS	Stainless steel, high nickel/copper alloys
Sleeve (cylinder liner)	316L SS	Stainless steel, high nickel/copper alloys
Piston	316L SS	Stainless steel, high nickel/copper alloys, silicon bronze
Piston ring	PTFE with bronze or carbon filling	PTFE with bronze or carbon filling
Piston ring spring (energizer if fitted)	316L SS	Stainless steel
Guide (rider) ring	PTFE, PTFE with bronze filling	PTFE, PTFE with bronze filling
Piston low pressure seal	Glass filled PTFE	Glass filled PTFE
Suction valve seat	316L SS	Stainless steel, high nickel/copper alloys
Suction valve	316L SS	Stainless steel, high nickel/copper alloys
Discharge valve (poppet valve)	PCTFE, Glass filled PTFE, stainless steel	PCTFE, Glass filled PTFE, stainless steel
Discharge valve spring (if fitted)	316L SS	Stainless steel
Discharge valve body	316L SS	Stainless steel, high nickel/copper alloys
Discharge valve gasket	Copper	Copper
Suction filter/strainer 1)	Copper, bronze, 316L SS	Copper, bronze, stainless steel, high nickel/copper alloys

1) Some pump styles may not have a suction filter/strainer.

7 Instrumentation

The instrumentation fitted to a cryogenic pump and pump installation depends upon the operational requirements of the installation and fluid being pumped. An example of pump instrumentation is shown in Figure 7. See Table 3 for an instrumentation list.

As a minimum, all pumps and pump installations shall have:

- Emergency stop buttons—Two emergency stop buttons are required: one near the pump and one remotely located. Either stop button shall stop the pump and return any actuated liquid or vapor valves to their fail safe position. Each button shall also activate the site alarm;
- Loss of prime/cavitation (TSHH1)—A loss of prime/cavitation shutdown system to prevent overheating and damage to the pump is required.

  This is normally a high temperature trip (TSHH1) on the pump discharge line. This requires an override for a short period during startup to allow the pump to be primed. The startup timer override should be set for the shortest time possible that will allow the pump to reliably detect prime.

  Another method of loss of prime/cavitation protection is a low current trip on single-speed pumps. However, current detection is difficult to configure and is less reliable on liquid hydrogen and variable speed pumps.

  While common on centrifugal pumps, differential pressure trips are usually unsuitable for typical reciprocating pump installations as the discharge pressure may not fall on loss of prime.

  The determination of appropriate safety integrity level (SIL) for the loss of prime shutdown system shall be based on a risk assessment. The system should then be designed and installed to meet this level;
- High discharge pressure trip (PSHH)—This shuts the pump down before the discharge relief valve lifts. The device measuring the pressure shall be an independent device from the pressure control.

  The determination of appropriate SIL for the high discharge pressure trip system shall be based on a risk assessment. The system should then be designed and installed to meet this level;
- Vaporizer discharge low temperature (TSLL3)—This is a temperature probe located after the vaporizer to ensure that the gas flowing downstream is not too cold, which risks embrittlement of nonresilient downstream equipment. See EIGA Doc 133 [9].

  The temperature sensing element should be installed at an appropriate distance downstream of any vaporizer bypass line return (to allow for mixing);
- Fire detection—A means of detecting a fire shall be provided and suitable for the process being monitored. This can be a flame detector, linear heat detector, UV detection, or other relevant technology. If fire is detected, any actuated valves feeding the pump shall close, the pump shall stop, and the site alarm shall be activated;
- Crankcase relief device—A crankcase relief device is required unless a risk assessment determines it is not needed. The crankcase relief device discharge shall be vented to a safe location;
- Distance piece (gland) purge—An inert purge of the distance piece is required unless a risk assessment determines it is not needed. The distance piece enclosure shall be vented to a safe location.

  This purge is fitted to prevent a flammable mixture from forming in the distance piece and also prevent the ingress of moisture. A manually adjusted flowmeter is often fitted to indicate and regulate this flow.

The potential for overpressurization of the warm-end drive should be considered and if necessary, a low pressure relief valve should be fitted with its discharge also vented to a safe location.

If the crankcase drive shares a purge with the distance piece, a nonreturn valve should be considered to prevent any liquid gland leakage being directed to the warm end;

- Low explosive limit (LEL) detector—A LEL detector is required if the pump is installed in an enclosed space such as a container. A LEL detector should be considered in open pump installations if in a congested area;
- Forced ventilation—If the pump is located in an enclosed space, forced ventilation shall be provided. In addition, ventilation fan run feedback is required for the actuated valves to open and the pump to run;
- Electrical isolation—A dedicated and lockable electrical disconnect for the pump motor and the control system shall be provided to allow for lock out/tag out (LOTO) for maintenance;
- Pump cooldown detection—The pump shall be adequately cooled down and degassed. Adequate cooldown ensures that the pump is filled with liquid and all parts are at the required temperatures so that the fits and clearances are per design. A startup permissive should be provided to prevent premature startup;

  Commonly used methods to determine that the pump is properly cooled down include:

  - Suction return low temperature permissive start/trip (TSLL1)
    - A temperature probe positioned to notify the system that the desired cooldown temperature has been reached and that the fluid condition remains acceptable during operation
    - The set point should be as low as possible consistent with the warmest liquid that might be expected in the storage tank (the higher the operating pressure of the tank, the warmer the potential liquid temperature) and
  - Cool down timer—The duration of the cooldown timer shall be adequate to ensure a minimum cooldown period of the pump prior to start up.

  Multiple factors including the system configuration, piping, pump type and size, and elapsed time since last operation, etc., affect the settings for cooldown time or required temperature to ensure the pump is adequately cooled down;

- Casing hot point detection—When any potential hot surface has been identified through a risk assessment, consideration shall be given to monitoring the hot surface for any unacceptable surface temperature (i.e., ignition temperature/temperature class) by a temperature element that touches the casing; and
- Gland leakage low temperature (TSLL2)—This a temperature probe located between the cold and warm end, which will notify the system of piston gland seal leakage. The pump shall be stopped as soon as a leak is detected.

Depending on the pump design and installation, the following additional instruments should be considered:

- Gland high temperature (TSHH2)—This a temperature probe located between the cold and warm end, which will give warning of possible cold- and/or warm-end mechanical issues. This temperature probe may be the same that is used for low temperature;
- High vibration (VSHH)—A vibration transmitter or switch that alarms and/or trips the pump in high vibration;
- Pressure control (PC)—A typical method of pressure control is the use of a pressure switch or pressure transmitter (pressure set point low and high [PSL and PSH]) to automatically control the pump;

- Discharge pressure gauges (PI)—Pressure gauges at the pump discharge outlet (after the pulsation device but upstream of the vaporizer) and downstream of the vaporizer for monitoring the discharge pressure of the pump and the pressure drop across the vaporizer;

- Pump prime at startup—Typical methods include starting the pump unloaded or through the use of an unloader valve. If an unloader valve is used during pump start up, its discharge shall be routed to a safe location (the tank vent stack); and

- Liquid vessel isolation—A typical method includes the use of a fail closed actuator using air to open the actuated cryogenic valve. This valve shall incorporate a means to ensure it is in the safe condition when performing maintenance. When actuated valves are used, they should be interlocked with the control system to ensure pumps cannot run when the valves are closed.

  NOTE—Fusible links, like plastic tubing, used to close an automatic valve in the event of a fire have been proven to be ineffective because the flame has to be directed right at the tubing. Including fusible links like plastic tubing so that the valves may close during a fire is recommended but little credit should be given in a risk analysis for this safeguard.

Double block and bleed valves should also be considered.

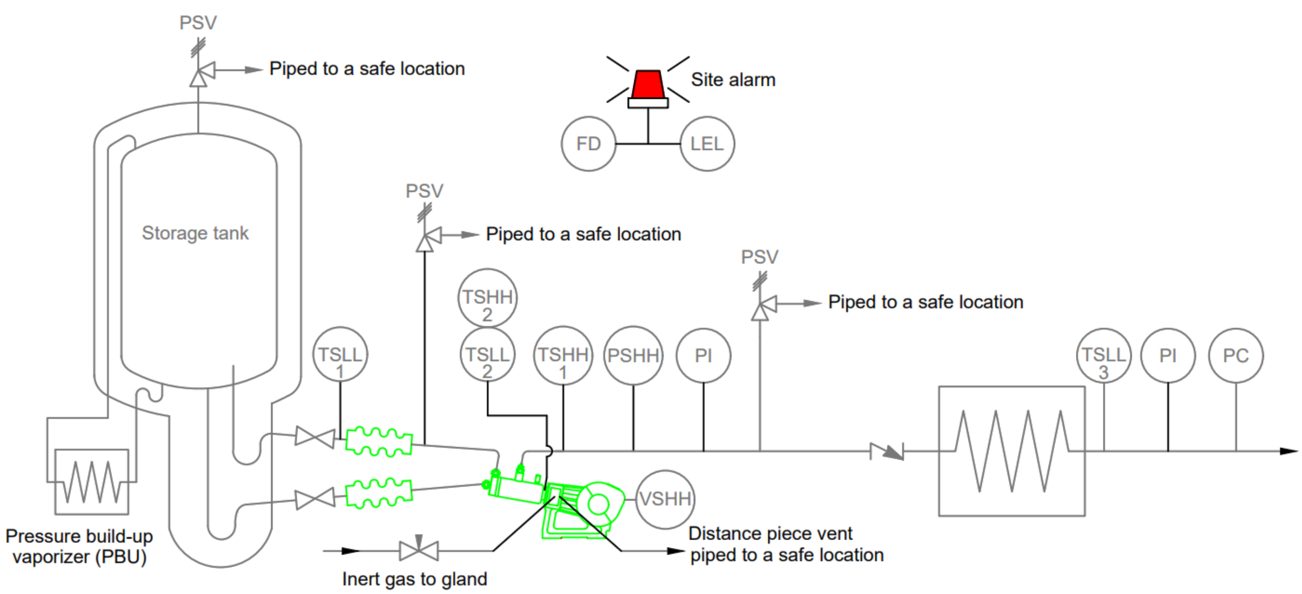

Figure 7—Example of pump instrumentation

Table 3—Instrument list

TAG	Instrument	Typical values	Status
TSLL1	Suction return low temperature permissive start		Optional
TSLL2	Gland leakage low temperature	–50 °C (–60 °F)	Mandatory
TSLL3	Vaporizer discharge low temperature	–30 °C [1)] (–20 °F)	Mandatory
TSHH1	Loss of prime shutdown system		Mandatory
TSHH2	Gland high temperature	+50 °C (+120 °F)	Optional
PSHH	High discharge pressure switch	Less than relief valve	Mandatory
VSHH	High vibration switch or transmitter		Optional

PI	Pressure gauge positioned at the pump discharge and after the vaporizer		Optional
PC	Pressure switch or pressure transmitter (pressure set point low and high (PSL and PSH)		Optional
FD	Fire detection		Mandatory
LEL	Low explosive limit detector	25% of the lower flammable limit (LFL)	Mandatory if installed in a container
[1)] Depending on downstream materials of construction and ambient temperatures.			

8 Insulation

Insulation or vacuum-jacketed pipe is commonly used on the piping to reduce the amount of heat in-leak to the liquid and for personnel protection. The requirement for any insulation depends on the liquid conditions and piping arrangement. When insulation is used, the type and material depend upon a number of items, including the fluid and volume of product pumped through the piping. Insulation shall be compatible with the fluid being pumped and condensed air where condensation can occur. Insulation of a suction line is recommended to minimize heat leak.

All cryogenic liquid hydrogen lines to and from the liquid storage tank are typically vacuum-jacketed.

9 Installation

9.1 General

Equipment is usually securely bolted to a concrete foundation.

Ensure that the pump components, which may have insulating gaskets, are all bonded to maintain electrical continuity to a common ground.

9.2 Layout

Delivery piping and cabling should be installed to allow adequate access for operation and maintenance, including pump removal and warming or purging before and after maintenance. Piping and cable routes should be considered early in the design stage to minimize (and combine where possible) the number of runs.

Cabling and conduit shall not be located under cryogenic pumps or piping where leakage can occur and shall not be installed in close proximity to liquid lines unless adequate protection is provided. The insulation materials of the wires can be subject to low temperature embrittlement and can fail.

The installation of the suction and suction return lines is critical to ensure liquid feed to the cold end, gas or liquid return to the tank, or gas vented to a safe location:

- The pump should be installed as near as possible to the liquid supply to minimize pressure drop;
- The piping between the tank and pump should be as short and direct as possible and have continuous slopes:
    - The suction line shall not be horizontal. It shall have a continuous upward or downward slope to facilitate gas return to the tank or vented to a safe location. Any high point in the suction line can result in trapped gas. The size (diameter) of the suction line should be equivalent to or slightly larger than the suction port of the pump. Lines that are too small create excessive friction loss and lines that are too large increase the external heat input by enlarging the heat exchange surface and

reducing the fluid speed. Elbows and bends should be minimized whenever possible and when used they should be designed with long radii

- The suction return line shall have a continuous upward slope to facilitate gas return to the tank or vented to a safe location to avoid trapping gas. Elbows and bends should be minimized whenever possible and when used they should be designed with long radii

- When a globe valve is used, a gas trap can be created if the line is not correctly sloped; and
- When ball valves are used, they should be full bore to minimize pressure drop and to prevent the creation of a gas trap at the valve.

9.3 Net positive suction head available

When determining net positive suction head available (NPSHa), the following shall be considered:

- Range of pump operation; and
- Acceleration head. With reciprocating pumps, the flow in the suction (and discharge) line fluctuates–accelerates and decelerates with each rotation of the crankshaft. Acceleration head is not a loss because the energy is recovered during deceleration. For information on calculating acceleration head, see API 674, *Positive Displacement Pumps–Reciprocating* [23].

NPSHa should always exceed the NPSHr indicated by the pump manufacturer, by at least the margin recommended by the pump manufacturer. This will prevent the release of vapor that could damage the plunger and the pump bearings.

NPSHa at the pump inlet can be increased by the following:

- Increasing the static liquid head (i.e., higher vessel position or maintaining a higher level of liquid in the vessel);
- Subcooling the liquid by increasing pressure in the vessel over the saturation pressure prior to operating the pump;
- Insulating the suction to minimize heat gain and on the return piping (vacuum-jacketed piping is recommended); and
- Reducing friction losses in the suction piping.

9.4 Piping

Piping should be adequately supported and allow for contraction and expansion due to temperature cycles.

The pump manufacturer shall provide the maximum acceptable external loads and moments on the pump connections from the user's piping. Suction, suction return line, and discharge piping should be attached to the pump so that the pump manufacturer's recommended nozzle loads are not exceeded when at ambient, cryogenic operating, or stand-still conditions.

Flexible metal hoses reinforced by external braiding or bellows may be used to manage piping contractions and elongations due to temperature swings. They are also often used on the suction side of pumps to isolate the tank and suction valves from pump vibration. When flexible metal hoses or bellows are used, they should be installed per manufacturer's recommendations so that they are not stretched or compressed (other than to accommodate the reduced pipe length during cooldown), twisted under operating conditions, or to accommodate misalignment.

Where there is any possible method of isolation in the discharge pipe, a full flow relief valve shall be provided. The relief valve shall be sized for full pump flow and shall not exceed the maximum allowable working pressure (MAWP) of the system. The relief valve shall vent to a safe location and shall be installed to protect against reaction forces.

A thermal relief valve shall be installed at any point where liquid can become trapped, for example between two valves, between a nonreturn valve and valve, or between pump discharge and a valve. This relief valve shall not exceed the MAWP of the system. The thermal relief valve shall vent to a safe location and shall be installed to protect against reaction forces.

Piping to relief valves that are upstream of the vaporizer should be taken from the top of the pipe and have a thermal standoff to prevent icing of the valve.

A nonreturn (check) valve should be fitted in the downstream piping to prevent backflow of high pressure gas. Manual or automatic drain and unloader valves can be fitted between this nonreturn valve and the pump discharge valve to aid priming or reduce potential mechanical damage to the pump discharge valve when idling under pressure.

Additional piping is required for pump installations as all potential fluid flow to the outside shall be collected and vented to a safe location so that the hazard zone remains unaffected. This potential fluid flow can include exhausts of any purges, safety valve discharges, drain and unloader valves (if equipped), packing leakage, and any other outcoming flows.

9.5 Area classification

The user shall specify the area classification according to the applicable codes, regulations, and standards (for example, NFPA 2, *Hydrogen Technologies Code;* NFPA 55, *Compressed Gases and Cryogenic Fluids Code;* NFPA 59A, *Standard for the Production, Storage, and Handling of Liquefied Natural Gas (LNG)*; NFPA 497, *Recommended Practice for the Classification of Flammable Liquids, Gases, or Vapors and of Hazardous (Classified) Locations for Electrical Installations in Chemical Process Areas*; ATEX Directive 1999/92/EC, *Risks from Explosive Atmospheres*) [24, 25, 26, 27, 28]. Such classification allows equipment protection levels to be determined and appropriate types of protection to be specified for each location.

The design of the installation, the selection of equipment, and its erection shall be carried out by trained personnel that are aware of the types of protection and installation practices, relevant regulations, and the general principles of area classification.

The relevant installation and operating instructions as well as applicable regulations shall be followed. Connections including power connection shall be made in accordance with installation and operating instructions. Additionally, electrical potential equalization is required for installations in classified areas. If electrical continuity cannot be guaranteed between any two components, a grounding point shall be added for equipotential bonding. Connections shall be secure against self-loosening and shall minimize the risk of corrosion, which can reduce the effectiveness of the connection.

Before starting any installation, it is necessary that the manufacturer provides equipment protection and use and installation instructions and that the user reviews and understands the instructions and any requirements.

9.6 Risk assessment

A risk assessment of the overall installation shall be performed to identify all possible hazards that may arise (such as leaks, hot surfaces, and electrical potential difference). This risk assessment should include, but is not limited to:

- duty of the pump (including pressure and flow);
- materials of construction;
- selection of lubricants;

- safety devices/instrumentation such as:
    - detection of pump cooldown
    - detection of leaks
    - detection of cavitation
    - detection of hot surfaces;
- installation location; and
- location and direction of vent discharges.

Full enclosures around pumps can create additional hazards that have the potential to go unnoticed until a fire or energy release occurs. If it is determined that a barrier or enclosure is required to protect personnel from a fire or energy release, a risk assessment should show that the barrier or enclosure does not create additional hazards such as a buildup of flammable gases in dangerous quantities due to restricted air flow, obstructed visibility, and limited emergency and maintenance access. Consult applicable codes for more information.

10 Operation

Instructions that define drying, standby, cooldown, startup, operation, shutdown, and emergency procedures shall be developed and available for each installation. A copy of these instructions should be reviewed with and made available to operators. Instructions should be periodically reviewed and updated as required through a management of change (MOC) process. Instructions should include, but not be limited to, details pertaining to the following items:

- Precautions to be followed to provide adequate liquid subcooling at the pump inlet to prevent cavitation such as minimum tank liquid level/pressure. Cavitation of the pump should be avoided as it can lead to seal degradation, overheating, and dry running, which can create critical hot surfaces and lead to an energy release;
- Appropriate position of all piping system valves for each mode of operation (cooldown, startup, operation, shutdown, etc.);
- Method used to check the pump shaft for freedom of rotation (warm and cold condition) and the frequency of these checks. The shaft freedom of rotation should be checked during commissioning and after pump maintenance. All freedom of rotation checks shall be performed only after the pump and motor have been isolated per LOTO procedures;
- Permissible process operating limits to avoid pump damage. For example, permissible discharge pressure ranges and temperature ranges;
- Pump normal operating conditions such as pump flow rate, purge and/or buffer gas flow rate, discharge pressure, and motor load (amps);
- Methods to determine if the pump loses prime during startup and normal operation and procedures to stop the pump before pump damage can occur; and
- Precautions to be followed to stop the pump if abnormal conditions are detected such as seal leakage or abnormal noises.

Purging is required before initial operation, and before and after opening a process line in order to prevent an explosive environment. The process line shall be free from air/oxygen before introducing a flammable fluid to the process line before initial operation and after opening a process line. The process line shall be free from flammable fluid prior to opening the process line to the ambient environment before maintenance. For liquid hydrogen applications, consideration shall be given to the selection of the purge gas so that it does not freeze.

A number of problems can occur during the operation of a cryogenic reciprocating pump. If NPSHr exceeds NPSHa at the pump inlet, NPSHa can be increased by steps detailed in 9.3.

The following is a list of common problems and solutions:

- If the pump fails to produce expected flow or pressure, check:
  - for sufficient cool down
  - that the feed, outlet, and return line isolation valves are open and undamaged
  - tank level and pressure
  - for blocked filters including those internal to the pump assembly (if applicable)
  - for suction line blockages
  - cold end for damaged, stuck, or leaking suction or discharge valve(s)
  - for worn or loose drive belts, gears, or other drive mechanism (as applicable);
  - for correct drive rotation
  - power supply;
- For seal leakage, check:
  - piston rings and gland seals for wear and running hours
  - that the gland purge or heater are functioning not allowing ice formation on the rod;
- For a noisy pump, check for:
  - damaged bearings, crosshead guides, or other mechanical issues; and
  - partial loss of prime/cavitation.

Periodically perform a visual inspection of permanently installed flexible metal hoses or bellows to ensure that these devices are in an acceptable condition.

11 Maintenance and repair

11.1 Maintenance

A maintenance program shall be developed based on the pump manufacturer’s recommendations and/or user experience. In addition, routine checks should be carried out during pump operation for signs of leakage, abnormal noises or vibration, increased temperatures, and other items that may need attention.

After a prolonged shutdown, maintenance, system modification, or repair is performed on a pump system, recommissioning may be required.

Verify direction of pump rotation before any unit that could have had motor wiring phase changes is placed into service. Wiring phase changes are possible after any motor/pump maintenance requiring lead disconnection at the motor or motor control center.

The pump shall be purged before and after maintenance to the cold end to remove any trace of the process medium that could be the source of a potentially explosive atmosphere. Purging should be considered before and after performing maintenance to the warm end.

For information on the use of nonsparking tools, see CGA PS-55, *CGA Position Statement on Use of Nonsparking Tools* [29].

11.2 Repair procedures

Repair procedures produced by the manufacturer, the user, or both shall be followed for any pump repair.

A work permit procedure shall be applied when maintenance or repair is performed on an operating or installed pump or for any other work in the classified area.

Additional specific precautions shall be adopted for pumps installed in confined spaces.

11.3 Parts

Only original equipment manufacturer (OEM) spare parts should be used. If not, the suitability of the spare part shall be approved by a competent person through a MOC process. Parts approved for use shall be adequately inspected, cleaned, handled, and stored.

12 References

Unless otherwise specified, the latest edition shall apply.

[1] EIGA Doc 159, *Reciprocating Cryogenic Pumps and Pump Installations for Oxygen, Argon, and Nitrogen*, www.eiga.eu

NOTE—This publication is part of an international harmonization program for industry standards. The technical content of each regional document is identical, except for regional regulatory requirements. See the referenced document preface for a list of harmonized regional references.

[2] EIGA Doc 148, *Stationary, Electric-Motor-Driven, Centrifugal Liquid Oxygen Pumps*, Compressed Gas Association, www.eiga.eu

NOTE—This publication is part of an international harmonization program for industry standards. The technical content of each regional document is identical, except for regional regulatory requirements. See the referenced document preface for a list of harmonized regional references.

[3] CGA G-6.3, *Carbon Dioxide Cylinder Filling and Handling Procedures*, Compressed Gas Association, Inc. www.cganet.com

[4] EIGA Doc 83, *Recommendations for Filling of Cylinders and Bundles with Carbon Dioxide*, www.eiga.eu

[5] NFPA 70, *National Electrical Code*®, National Fire Protection Association. www.nfpa.org

[6] ATEX Directive 2014/34/EU, *equipment and protective systems intended for use in potentially explosive atmospheres*, European Commission. www.ec.europa.eu

[7] CGA G-5.4, *Standard for Hydrogen Piping Systems at User Locations,* Compressed Gas Association, Inc. www.cganet.com

NOTE—EIGA did not participate in this international harmonization program for industry standards.

[8] EIGA Doc 121, *Hydrogen Pipeline Systems,* www.eiga.eu

NOTE—This publication is part of an international harmonization program for industry standards. The technical content of each regional document is identical, except for regional regulatory requirements. See the referenced document preface for a list of harmonized regional references.

[9] EIGA Doc 133, *Cryogenic Vaporization Systems—Prevention of Brittle Fracture of Equipment and Piping,* www.eiga.eu

NOTE—This publication is part of an international harmonization program for industry standards. The technical content of each regional document is identical, except for regional regulatory requirements. See the referenced document preface for a list of harmonized regional references.

[10] ASME B31-All Parts, *Pressure Piping,* American Society of Mechanical Engineers. www.asme.org

[11] EN 13480-1, *Metallic Industrial Piping – Part 1: General,* European Organization for Standardization. www.cencelec.eu

[12] API Standard 607, *Fire Test for Quarter-turn Valves Equipped with Nonmetallic Seats,* American Petroleum Institute. www.api.org

[13] ISO 10497, *Testing of valves—Fire type-testing requirements,* International Organization for Standardization. www.iso.org

[14] ISO 21028, *Cryogenic vessels—Toughness requirements for materials at cryogenic temperature, Part 1: Temperatures below -80 degrees C,* International Organization for Standardization. www.iso.org

[15] ISO 21010, *Cryogenic vessels—Gas/material compatibility,* International Organization for Standardization. www.iso.org

[16] ASME B31.3, *Process Piping,* American Society of Mechanical Engineers. www.asme.org

[17] ASME B31.12, *Hydrogen Piping and Pipelines,* American Society of Mechanical Engineers. www.asme.org

[18] EIGA Doc 6, *Safety in Storage, Handling and Distribution of Liquid Hydrogen,* www.eiga.eu

[19] EIGA Doc 33, *Cleaning of Equipment for Oxygen Service,* www.eiga.eu

NOTE—This publication is part of an international harmonization program for industry standards. The technical content of each regional document is identical, except for regional regulatory requirements. See the referenced document preface for a list of harmonized regional references.

[20] CGA G-5.3, *Commodity Specification for Hydrogen*, Compressed Gas Association, Inc. www.cganet.com

[21] CGA G-19.1, *Standard for Natural Gas Supply Systems,* Compressed Gas Association, Inc. www.cganet.com

[22] CGA H-3, *Standard for Cryogenic Hydrogen Storage,* Compressed Gas Association, Inc. www.cganet.com

[23] API Standard 674, *Positive Displacement Pumps – Reciprocating,* American Petroleum Institute. www.api.org

[24] NFPA 2, *Hydrogen Technologies Code,* National Fire Protection Association. www.nfpa.org

[25] NFPA 55, *Compressed Gases and Cryogenic Fluids Code,* National Fire Protection Association. www.nfpa.org

[26] NFPA 59A, *Standard for the Production, Storage, and Handling of Liquefied Natural Gas (LNG),* National Fire Protection Association. www.nfpa.org

[27] NFPA 497, *Recommended Practice for the Classification of Flammable Liquids, Gases, or Vapors and of Hazardous (Classified) Locations for Electrical Installations in Chemical Process Areas,* National Fire Protection Association. www.nfpa.org

[28] ATEX Directive 1999/92/EC, *minimum requirements for improving the safety and health protection of workers potentially at risk from explosive atmospheres*, European Commission. www.ec.europa.eu

[29] CGA PS-55, *CGA Position Statement on Use of Nonsparking Tools,* Compressed Gas Association, Inc. www.cganet.com