INSTALLATION GUIDE FOR STATIONARY, ELECTRIC-MOTOR-DRIVEN, CENTRIFUGAL LIQUID OXYGEN PUMPS

AIGA 055/08

GLOBALLY HARMONISED DOCUMENT

Based on CGA G-4.7

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Contents **Page**

Table

Figures

1 Introduction

As a part of a programme of harmonization of industry standards, the Asia Industrial Gases Association (AIGA) has adopted the original Compressed Gas Association (CGA) standard G4.7. This standard is intended as an international harmonized standard for the worldwide use and application by all members of AIGA, CGA, EIGA, JIMGA and ANZIGA. The AIGA version has the same technical content as the CGA edition, however, there are editorial changes primarily in formatting, units used and spelling. Also references to national regulatory requirements replace U.S. regulations.

Pumping liquid oxygen, like many current processes, is accompanied by some degree of hazard that needs to be recognized and addressed. The hazards include liquid under pressure, cryogenic temperatures, volume and pressure increases due to vaporization, and the ability of oxygen to accelerate combustion. An incident can result in (1) burning through a pump casing or adjacent piping, releasing a powerful jet of liquid or gas with entrained molten metal and metal oxides; or (2) the rupturing of motor housings, beltboxes, or gearboxes with explosive force, throwing metal fragments like shrapnel. Either can be fatal to unprotected personnel and can damage adjacent equipment. The danger zone can extend to 100 ft (30.5 m) or more.

2 Scope and purpose

2.1 Scope

2.1.1 Current industrial practice

This guide contains a summary of current industrial practices and is based on the combined knowledge, experience, and practices of major liquid oxygen producers through the consensus process of CGA. It is written as a reference document when specifying stationary, electric-motor-driven, centrifugal liquid oxygen pump designs and installations, and as a guide for the operation and maintenance of this equipment. It is not intended to cover other types of pumps such as reciprocating or vehicle mounted. While many parts of this guide can be used as the basis for those other types of pumps, it is not written considering all the special features of those designs. In addition, it does not attempt to include design and installation criteria for all cryogenic pumps but focuses on those specifically related to oxygen safety. Most industrial experience involves pump installations where the liquid oxygen concentration is 95 mol % or greater. The installer shall exercise sound engineering judgment when specifying pumping equipment for oxygen-enriched liquid mediums with oxygen concentrations between 25 mol % and 95 mol %.

2.1.2 Engineering judgment

Some of the practices presented represent conservative compromise, and not all situations are described. The designer is cautioned that this guide is not a design handbook and does not eliminate the need for competent engineering judgment and interpretation. It does not purport to address all the safety problems associated with liquid oxygen pump use. It is the responsibility of whoever uses this guide to consult with qualified technical personnel, to establish appropriate safety and health practices, and to determine the applicability of regulatory limitations before use.

2.1.3 Shall and should

Although this guide is not intended to be a mandatory code, the word “shall” is frequently used. When used, it implies very strong concern that the particular practice be followed for safety reasons. The use of the word “should” implies that the referenced practice is commonly followed but recognizes other safe practices may be used.

2.2 Purpose

The purpose of this guide is to furnish qualified technical personnel with pertinent technical information to use in designing new liquid oxygen pump installations. It emphasizes considerations that will enhance safe, reliable operation of liquid oxygen pumps. Refer to CGA P-8 and AIGA 056/08, *Safe Practices Guide for Air Separation Plants* [1, 9].[1] This publication is not intended as a specification for the design of oxygen pumps.

3 Definitions

For the purposes of this publication, the following definitions apply.

3.1 Cold end
Pump assembly through which the cryogenic liquid passes and is elevated in pressure. When the pump is in service, it reaches the temperature of the fluid being pumped.

3.2 Containment enclosure
Structure or device that typically is insulated and contains or encases the cold end such as a pit, pump box, duct, or pump coldbox.

3.3 Distance piece
Carrier frame or intermediate support between the cold end and the warm end.

3.4 Incident
Pump failure involving an energy release such as fire, explosion, dispersion of molten metal, or metal fragments, or any combination.

3.5 Pump system
Pump, driver, any belt or gear speed increaser, piping from the prior shutoff valve to the downstream shutoff valve or check valve, control devices, and relief valves.

3.6 Purge gas
Ambient temperature, dry, oil-free air; nitrogen; or argon used to sweep away or prevent concentrated oxygen or moisture laden air.

3.7 Qualified technical personnel
Persons such as engineers and chemists who, by virtue of education, training, or experience, know how to apply physical and chemical principles involved in the pumping of cryogenic liquids and the reactions between oxygen and other materials.

3.8 Warm end
Motor, gearbox, beltbox, and bearing housing.

NOTE—The bearing housing may be separate or incorporated into one of the other warm-end components.

4 Safety considerations

4.1 Properties of oxygen

4.1.1 Hazards

Handling liquid oxygen involves hazards associated with its strong oxidizing properties, the cryogenic temperature of the liquid and vapour, and the pressure-producing potential of the vaporization and liquid expansion processes.

4.1.2 Oxygen cleaning

Equipment shall be cleaned for oxygen service in accordance with an approved cleaning procedure. The cleaning shall be done by individuals qualified to clean oxygen systems. Before use, all equipment that is normally in contact with oxygen shall be degreased and, if stored, shall be protected from contamination and corrosion and labelled to indicate it is suitable for oxygen service. Refer to CGA G-4.1, *Cleaning Equipment for Oxygen Service* [2] and AIGA 012/04 *Cleaning of equipment for oxygen service* [10].

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

4.1.3 Contamination

Personnel working on or handling parts or equipment that can come in contact with oxygen shall wear only clean gloves and clothing and shall use only new slings and clean handling equipment.

4.2 Oxidation hazards

4.2.1 Stability

Although oxygen in gaseous or liquid form is stable and non-flammable, it is classified as an oxidizer.

4.2.2 Flammability

Materials that burn in air will burn much more vigorously and at a higher temperature in oxygen or in oxygen-enriched atmospheres. Refer to CGA G-4, *Oxygen* [3] and AIGA 005/04 *Fire hazards of oxygen and oxygen enriched atmospheres* [11]. Some combustibles such as hydrocarbon oils burn with explosive violence in oxygen-enriched atmospheres. Materials with greater resistance to ignition and lower rates of combustion shall be selected.

4.2.3 Ignition temperatures

Ignition temperatures are reduced in oxygen-enriched atmospheres. Some materials that do not burn in air burn readily and vigorously in an oxygen-enriched environment.

4.2.4 Clothing

Absorbent material such as clothing can become saturated with oxygen and readily ignite and burn rapidly. The hazard can continue for some time after exposure to the oxygen source. If exposed to oxygen vapours, bulky clothing should be removed or the individual should stand in an open area or otherwise avoid ignition sources for 30 minutes to allow excess oxygen to desorb from the clothing.

4.2.5 Ground surface

The ground surface in the vicinity of oxygen pump installations shall be inorganic material compatible with liquid oxygen. Asphalt and other hydrocarbon-based materials constitute a hazard and if saturated with liquid oxygen become explosive when ignited by a falling object or by any form of friction such as tire friction. Stepping on oxygen spill areas or rolling equipment across them can result in ignition.

4.2.6 Hydrocarbon lubricants

Hydrocarbon lubricants constitute a serious hazard in the presence of oxygen and should not be used where they could come in contact with oxygen. If it is necessary to use hydrocarbon lubricants in an oxygen pump installation, precautions such as connecting a gas purge to the bearing housing shall be taken to ensure that the lubricants cannot come in contact with oxygen (see 4.5.5 and 5.5.3).

4.3 Cryogenic hazards

4.3.1 Boiling

Liquid oxygen boils at –297 °F (–183 °C) at atmospheric pressure.

4.3.2 Burns

Skin contact with spilled or spraying liquid oxygen, cold vapour, or valves, couplings, piping, or other cold surfaces can cause severe frostbite or cryogenic burns.

4.3.3 Ice

Moisture condenses and freezes on exposed cold surfaces causing valves, couplings, and safety devices to freeze open or shut, preventing proper operation.

***WARNING:** Ice buildup can block normal ventilation openings causing higher oxygen concentrations and diverting flow into unwanted spaces.*

4.4 Vaporization and pressure hazards

4.4.1 Volume

One volume of liquid oxygen expands to 856 volumes of gas at ambient conditions. Regardless of the pressure, liquid oxygen cannot exist as a liquid at temperatures above –181 °F (–119 °C), which is known as its critical temperature.

4.4.2 Trapped liquids

Liquid oxygen constantly absorbs heat through the container walls causing boiling. When liquid or cold gas is trapped within a vessel or a section of piping, the rapid rise in pressure within the contained space can cause the equipment to rupture. To prevent such failures, thermal relief valves shall be provided in each section of piping or equipment within which cold oxygen could be trapped.

4.4.3 Housekeeping

Good housekeeping in and around the area of a liquid oxygen pump installation is an overall requirement. Thermal relief valves vent gas to the atmosphere so there is always the danger of increased concentrations of oxygen. Combustible materials shall not be stored in the area.

4.4.4 Dispersion

Cold, gaseous oxygen and liquid oxygen are considerably heavier than air and accumulates in pits, trenches, or other depressions in the ground surface.

4.5 Incidents

4.5.1 History

A review of known liquid oxygen pump incidents revealed that the most common contributing factors have been cold-end materials of construction, shaft seal leakage, and hydrocarbon lubricants.

4.5.2 Cold-end incidents

Pumps built before the 1980s were normally constructed of aluminium or aluminium bronze. Both materials can be readily ignited in an oxygen atmosphere and cause an uncontrolled energy release. Conversion of pump housings and impellers to a tin bronze material significantly reduced the frequency of pump incidents related to materials of construction. However, it should be noted that the material changes have not totally eliminated ignitions since elements can rub or foreign particles can be caught between moving parts, and the installation designer should bear this in mind.

4.5.3 Warm-end incidents

Most recent incidents have been largely attributed to prolonged or serious seal leaks and the presence of hydrocarbon lubricants in the warm end of the pump and driver train. Shaft seal leakage can result in high oxygen concentrations in the pump bearing housing leading to an energy release. The pump bearing housing could be the motor, gearbox, beltbox, or a separated bearing housing attached to the beltbox or installed in the distance piece depending on pump design.

4.5.4 Ice buildup

The accumulation of ice that occurs when moist air comes in contact with cold surfaces on the distance piece between the cold end and the warm end can cause bridging that can channel oxygen leakage to the warm end and increase oxygen concentrations in the bearing housing area. Seal leakage and ice buildup should be monitored and corrected to reduce the potential for pump incidents.

4.5.5 Lubricants

Use of oxygen-compatible lubricants probably reduces pump incidents; however, they are inferior to hydrocarbon lubricants with regard to lubricity and are often hygroscopic, causing corrosion and a decrease in bearing performance and reliability. Oxygen-compatible lubricants shall be used in gearboxes or pump arrangements that have large lubricant inventories. Hydrocarbon greases are generally used in antifriction bearings for better reliability since the amount of lubricant is small. In that case, installation of an inert gas purge on the pump bearing housing is the safest and most cost-effective method of preventing oxygen accumulation in the bearing housing.

4.6 Reapplication of used equipment

The installer of liquid oxygen pumps is responsible for the safe installation of new and used equipment. Used pumps shall be investigated to verify the age, operating condition, materials of construction, cleanliness, previous service, type of lubricants used, and suitability for the proposed application. Efforts should be made to upgrade used equipment when reapplied to new installations or applications to conform to current design practice. The installer should enlist the assistance of qualified technical personnel, if necessary, to confirm the used equipment is acceptable for oxygen service.

5 Pump design

5.1 User caution

5.1.1 Design

This publication is not a design handbook and, therefore, is not a substitute for competent engineering judgment and interpretation. It is suggested that the user review any special problems or concerns with the pump supplier who should be more knowledgeable in these special practices.

5.1.2 Special designs and applications

For pumps not covered by these guidelines, appropriate engineering design and operation practices shall be used. Special applications, designs, or concerns shall be reviewed with the equipment supplier and qualified technical personnel.

5.1.3 System concerns

The pump is part of a system, and appropriate installation safety criteria for the entire pump system shall be followed.

5.2 Materials of construction

5.2.1 Bronze

The use of pumps made only of bronze (impeller, backplate, and housing) has nearly eliminated incidents of ignition and sustained combustion from severe internal rubs, and there have been no incidents where burn-through has occurred. Aluminium bronze shall not be used (see 5.3.3.1). Although the use of all-bronze pumps minimizes the potential for ignition and sustained combustion, there is still uncertainty; therefore, a prudent choice of materials of construction for each part is required. A sound technical knowledge of materials, design practices, test methods, and operational techniques shall be applied.

5.2.2 Sources of ignition

The following ignition sources could typically promote ignition in liquid oxygen pumps:

– extended periods of pump operation without sufficient liquid;

– bearing, shaft, or impeller failure resulting in severe internal rubbing;

- impact from an internal foreign particle; and
- mechanical friction due to excessive vibration, particles trapped in running clearances, improper assembly, or excessive piping loads on pump flanges.

5.2.3 Compatibility data

Acceptable materials of construction are based in part on American Society for Testing and Materials (ASTM) standards, ASTM Standard Technical Publications, and information compiled by the ASTM G-4 Committee [4, 5].

While not specifically for centrifugal liquid oxygen pumps, ASTM and other published sources can be used by the designer as a guide in the selection of materials. Tests show that ignition is more likely with increasing oxygen pressures and temperatures. In a pump, ignition is generally less likely due to the cryogenic cooling and the relatively high required ignition temperatures. However, this is not true at potential rubbing surfaces. Special material combinations shall be used at these surfaces due to the potential for high friction-induced temperatures.

The acceptability of some materials can be based on actual operating experience in oxygen equipment.

5.2.4 Ideal material properties

The ideal properties to minimize the potential of ignition and to inhibit sustained combustion are:

- high ignition temperature;
- high thermal conductivity; and
- low heat of combustion.

In addition to oxygen compatibility, the materials and construction shall be suitable for:

- cryogenic operation;
- the function intended for the part;
- containment of pressurized liquid and gaseous oxygen; and
- mechanical strength.

5.3 Cold-end components

5.3.1 Typical pump

A typical cross-sectional drawing of a centrifugal oxygen pump with a cold mechanical face seal in Figure 1 identifies the common pump components.

5.3.2 Acceptable materials

A summary of the acceptable materials of construction is given in Table 1.

5.3.3 Copper alloys

The most suitable materials for wetted components (i.e., housings, impellers, inducers, wear rings, diffusers, shims, and backplates) are copper alloys with a minimum of 80% copper and a maximum of only a trace amount of aluminium (0.1% maximum). Typical materials are tin and leaded bronzes. In the past, many materials have been used in liquid oxygen pumps, but the use of materials that have relatively high heats of combustion and low ignition temperatures such as aluminium and aluminium bronze is no longer acceptable.

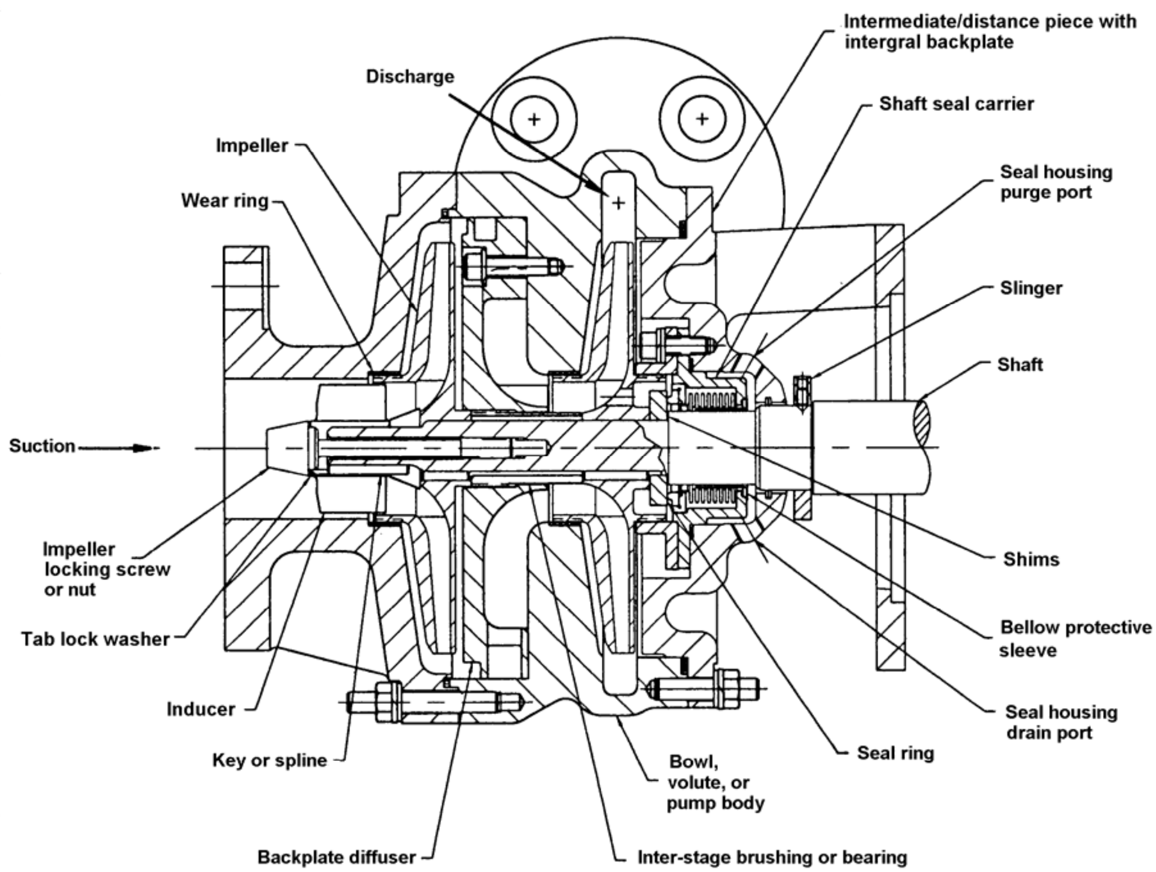


Figure 1—Components of a centrifugal oxygen pump with a cold mechanical face seal

5.3.3.1 Aluminium bronzes

Aluminium bronzes were used at one time in centrifugal liquid oxygen pumps because of their exceptionally high tensile strength. Cast aluminium bronzes typically range from 6.0% to 11.5% aluminium and from 0.8% to 5.0% iron. These elements have relatively high heats of combustion. If aluminium bronze ignites in an oxygen-rich atmosphere, it is practically impossible to extinguish; therefore, it is no longer acceptable.

5.3.3.2 Bronze cast alloys

Originally, the term bronze was used for copper alloys whose principal or only alloying element was tin. Broadly speaking, bronzes are copper alloys in which the major alloying element is not zinc or nickel. Today, to be technically correct, the term should be used with a modifying adjective. There are four main bronze cast alloys: tin bronzes, leaded and high-leaded tin bronzes, nickel-tin bronzes, and aluminium bronzes.

5.3.4 Copper-nickel alloys

Copper-nickel alloys exhibit outstanding resistance to promoted ignition/combustion and excellent castability, corrosion resistance, and mechanical properties over a range of temperatures, making them suitable for casings and impellers. Copper-nickel alloys are defined as containing a minimum of 67% copper, with the balance predominantly nickel.

Table 1—Acceptable materials of construction for centrifugal liquid oxygen pump (see 5.3)
(Refer to Figure 1 for typical pump nomenclature.)

Part	Materials
Bowls, volute, or pump body Backplates Impellers Inducers Diffusers Wear rings	Copper alloy, copper-nickel alloy, or nickel-copper alloy 1)
Protective sleeves Interstage bushings or bearings	Teflon® (polytetrafluoroethylene [PTFE]), copper alloy, copper-nickel alloy, or nickel-copper alloy
Impeller bolts Fasteners	Austenitic stainless steel, copper alloy, copper-nickel alloy, or nickel-copper alloy
Tab-lock-washers Shims Lock-wire	Copper alloy, copper-nickel alloy, or nickel-copper alloy
Bellows	Austenitic stainless steel or nickel alloys
Seal ring	Stainless steel, tungsten carbide, or ceramic
Shafts	Stainless steel, nickel-copper alloy
Gaskets	Filled PTFE, flexitallic stainless steel with graphite fillers
O-rings	PTFE, Buna-N 2), Viton®
Labyrinth Seal 3)	Silver, copper alloy, PTFE or babbitt against nickel-copper alloy or stainless steel
Filter/strainer 3)	Nickel-copper alloy mesh screen preferred or stainless steel 4); nickel-copper alloy or stainless steel support

1) Monel® is an example of a nickel-copper alloy.

2) If completely enclosed and at a pressure less than 500 psig (3450 kPa).[2] Refer to ASTM G63 [7].

3) Not shown in Figure 1.

4) See 6.5.6.

5.3.5 Nickel-copper alloys

Nickel-copper alloys exhibit excellent oxygen compatibility and high strength, making them suitable for protective sleeves, bushings, and bolts. Nickel-copper alloys are defined as having a minimum nickel content of 60%, with the balance predominantly copper.

5.3.6 Stainless steels

Stainless steels suitable for cryogenic applications are acceptable for components where there is no potential for stainless steel-to-stainless steel rubbing. If this potential exists, the mating material shall be in accordance with 5.3.7. Shafts, fasteners, washers, locking devices, drive keys, and seal rings are typically made of stainless steel. It should not be inferred that stainless steel pump housings or impellers are generally acceptable. Stainless steel's high heat of combustion makes it undesirable for normal use. It should be used only with special design considerations such as a suitable liner in a housing.

[2] kPa shall indicate gauge pressure unless otherwise noted as (kPa, abs) for absolute pressure or (kPa, differential) for differential pressure. All kPa values are rounded off per CGA P-11, *Metric Practice Guide for the Compressed Gas Industry* [6].

5.3.7 Thin internal parts

Thin internal parts should be avoided because susceptibility to ignition increases as thickness is reduced.

Stainless steels and aluminium alloys should not be used for shims. Thin shims of these materials are more likely to ignite and burn. Shims shall be made of copper alloys, nickel-copper alloys, or nickel-based alloys (see Table 1).

Locking wire and other components thinner than 0.032 in (0.8 mm) are not recommended for internal components. If they must be used, the material shall be copper alloy, nickel-copper alloy, or nickel-based alloy (see Table 1).

5.3.8 Potential rubbing surfaces

Silver, copper alloys, nickel-copper alloys, PTFE, or babbitt shall be used in one of the mating surfaces where metal-to-metal rubbing is likely to occur such as in a labyrinth-type shaft seal, inter-stage bushing, or inter-stage bearing.

5.4 Mechanical design

5.4.1 Clearances

Clearances between rotating and stationary parts shall be as large as practical. The maximum possible contaminating particle size shall be taken into consideration.

5.4.2 Fastening

All internal fasteners shall have a locking device. Impeller attachment fasteners shall use a positive-type locking device such as tab-lock washers or lock wire. Interference fits are not considered to be locking devices; however, heavy interference fits may be used to install wear rings in the pump casing. The axial movement of the pump shaft shall be positively limited by its bearings.

5.4.3 Shaft seals

Commercial pump experience has been with either a mechanical face or a labyrinth-type seal. The designer shall consider that seal leakage creates a serious hazard that increases with the amount of leakage. Mechanical face seals in cryogenic pumps can fail unpredictably and leakage rates can change abruptly.

A slinger or other deflection device shall be used to prevent direct impingement of shaft seal leakage on the driver bearing. This is to prevent the rapid freezing and failure of the bearing in the event of a shaft seal leak.

The mechanical seal housing should have a purge port. Purging the external surface of the seal with dry gas can increase seal life by preventing moisture and ice from accumulating at the seal face. The manufacturer shall provide the port, but the user has the option of connecting a purge gas to it. The user’s experience with pump reliability in similar service should determine whether it is used.

The mechanical seal housing also shall have a vent/drain port. Venting leakage out of and away from the housing reduces the hazard, and measuring the vented flow can aid in detecting the onset of seal failure.

For functional and strength reasons, mechanical seals use bellows that are typically made of relatively thin metal. A protective sleeve shall be used between the bellows and the shaft. Thin parts are more likely to ignite from rubbing or particle impact. The protective sleeve material shall be in accordance with Table 1.

The mechanical seal design shall prevent metal-to-metal rubbing between the seal carrier and the rotating seal ring over the maximum possible axial movement of the bellows.

Labyrinth shaft seals shall be treated as systems engineered for the particular application. The labyrinth shaft seal uses a small, controlled leakage of a buffer gas to prevent liquid leakage. The buffer gas supply pressure should be slightly higher than the liquid oxygen pressure at the shaft seal. Typically, a differential pressure regulator is used to control the supply pressure. The buffer gas leaks into the liquid oxygen stream and to the atmosphere.

If contamination of the liquid oxygen is to be prevented when using a labyrinth seal, an oxygen buffer gas is used. If the small leakage of oxygen gas to the atmosphere is not acceptable, a dual gas labyrinth seal design may be used. In this design, the shaft seal has three axially spaced gas ports. At the pump end of the shaft, the oxygen buffer supply prevents liquid leakage. At the driver end of the shaft seal, an oxygen-compatible purge gas supply prevents oxygen leakage to the atmosphere. The middle port is the mixture outlet port, and it is used to vent the oxygen and purge the gas mixture to a safe area.

5.4.4 Ice buildup

Special design consideration should be given to preventing ice buildup on the pump and bridging to the driver or bearing housing. The buildup could allow oxygen from a shaft seal leak to be forced directly into the driver. Ice buildup and bridging is more likely to occur in continuous or extended duty pumps than in intermittent duty pumps. It can also occur when a pump is maintained in a cold standby condition.

An insulating shield or thermal barrier between the pump cold end and the driver can be effective for continuous duty applications. If the distance piece is enclosed, it shall be purged with a purge gas and must be vented in a way that there is no pressure buildup from a seal leak.

5.5 Pump shaft bearings

5.5.1 Bearing types

Most common industrial experience is with rolling element bearings, which are external to the cold end. Internal bearings/bushings in contact with oxygen shall be of special design and specially tested for oxygen and cryogenic compatibility before being put into liquid oxygen service.

5.5.2 Cold soak

Overcooling of bearings external to the cold end can be avoided by good design and suitable operating techniques. Special consideration shall be given to the design of an intermediate thermal barrier between the cold end and the warm end (motor, gearbox, or beltbox). The pump shall not be kept in a cooled, non-operating, standby mode for a period longer than is specified in the manufacturer's manual and as agreed to by the purchaser. The bearing closest to the cold end should have a heater if subjected to icy conditions when exposed to prolonged periods of operation or cold standby.

5.5.3 Lubrication

5.5.3.1 Minimum lubricant operation

A suitable low temperature lubricant shall be used for the bearing closest to the pump cold end. As a minimum, the lubricant shall be suitable for operation at –40 °F (–40 °C). This is especially important for grease-lubricated bearings. They are more susceptible to lubricant freezing damage from excessive and prolonged pump cooldown. The temperature value is somewhat arbitrary and is based on the availability of good low temperature greases.

5.5.3.2 Oil lubricants

Oil lubricants are very difficult to contain because of their lower viscosity. They flow along shafts, through tight clearances, and through seals. Therefore, hydrocarbon oils shall not be used in an oxygen pump area.

5.5.3.3 Oxygen-compatible lubricants

Special design consideration shall be taken to ensure that potential oxygen leakage cannot come into contact with hydrocarbon lubricants. When this cannot be assured, approved oxygen-compatible lubricants shall be used. Oxygen-compatible lubricants shall pass ASTM criteria [7]. If a purge gas system is used to prevent oxygen from contacting any nonoxygen-compatible lubricant, it shall be specifically designed and tested to verify that the lubricated equipment is adequately isolated from the oxygen-wetted area.

5.5.3.4 Corrosion protection

Oxygen-compatible lubricants provide virtually no corrosion protection as compared to hydrocarbon-based lubricants. They have poor wetting properties and do not provide a corrosion protective film. Many bearing failures have occurred due to corrosion caused by atmospheric moisture. Either a method of corrosion protection or a dry purge is recommended. Oxygen-compatible greases are inferior to hydrocarbon-based greases for centrifugal pump bearings because their high density makes them less suitable for the high speed lubrication requirements of centrifugal pump bearings (see 4.5.5).

5.5.3.5 Regreasing bearings

Permanently greased bearings are normally preferred, although higher speed applications and larger bearing sizes can require regreaseable bearings for acceptable bearing life. Excessive or improper regreasing can result in large accumulations of grease in the bearing housing. The grease drain plug shall be removed when regreasing so that excess or old grease is removed through the drain rather than being forced into the main bearing housing. The manufacturer’s maintenance procedures shall be followed. This includes the amount of grease and number of operating hours between regreasings. Grease fittings should be removed and plugged with a suitable plug to prevent unwarranted or unauthorized grease application. Regreasing should be performed only by personnel specifically trained in these requirements.

5.6 Pump motors

5.6.1 Motor type

Electric motors shall be of the totally enclosed fan cooled (TEFC) type, where an externally mounted fan provides cooling air over the outside of the motor. Open type motors, i.e., open drip proof (ODP), weather protected one (WP1), or weather protected two (WP2) shall not be used.

5.6.2 Direct coupled or rigid coupled

Motors directly coupled to the pump shall have a positive shaft axial location. The pump end bearing should be lubricated with a suitable low temperature lubricant as described in 5.5.3.1.

6 Installation

6.1 Primary installation safety method

6.1.1 Selection

In addition to only using the pump materials defined herein as acceptable, the user shall select and *use at least one of the four following methods* as the primary means of ensuring a safe installation.

6.1.1.1 Purge gas systems

Use an engineered purge gas system for hydrocarbon-lubricated bearings and reservoirs in close proximity to the pump. In direct coupled pumps, both motor bearings shall be purged. In beltbox pumps, the beltbox bearings shall be purged. The beltbox design shall be carefully examined since its bearings might be external to the box. In gearbox-driven pumps, the gearbox bearings as well as the gearbox housing and reservoir shall be purged. Purge gas systems shall be completely independent of the seal system. They shall have their own pressure reducers from the purge gas header to prevent any possibility of oxygen from the seal system being routed to the bearing housing.

6.1.1.2 Barriers

Use barriers or shields to protect personnel and equipment in the event of an incident (see 6.3).

6.1.1.3 Hazard zones

Define and maintain a hazard zone in accordance with 6.2 and restrict entry into it. This is probably the least preferred method because it relies on a distance that cannot be easily defined and on limited access procedures. If used, it shall be a logically thought-out decision that considers all the factors.

6.1.1.4 Oxygen-compatible lubricants

Use oxygen-compatible lubricants instead of hydrocarbon lubricants in the areas mentioned in 6.1.1.1. It must be cautioned that there is a lack of complete data to support this method. While this method removes the hydrocarbon lubricants that have been the source of fuel for recent incidents, there is concern that other materials such as motor materials or belt materials could provide a fuel source. There are no known cases of this; however, there have been no studies conducted to prove this could not happen.

6.1.2 Combinations and additional steps

The use of acceptable cold-end materials and one of the methods from 6.1.1 are considered the minimum required initial basic steps. Allowing a choice acknowledges the fact that different companies use different methods, and even individual companies use different methods in different situations. Other precautions may be added to the selected primary method as appropriate. At times, more than one primary method may be used in a given installation.

6.1.3 Logical precautions

The use of one or many safety methods should not result in the assumption that all risk is gone. This means that on new installations any easy and logical additional steps that increase the safety margin should be incorporated. For example, whenever possible, site a new pump in a location that is not normally busy, even if it has purged bearings.

6.2 Hazard zones

6.2.1 Historic definition

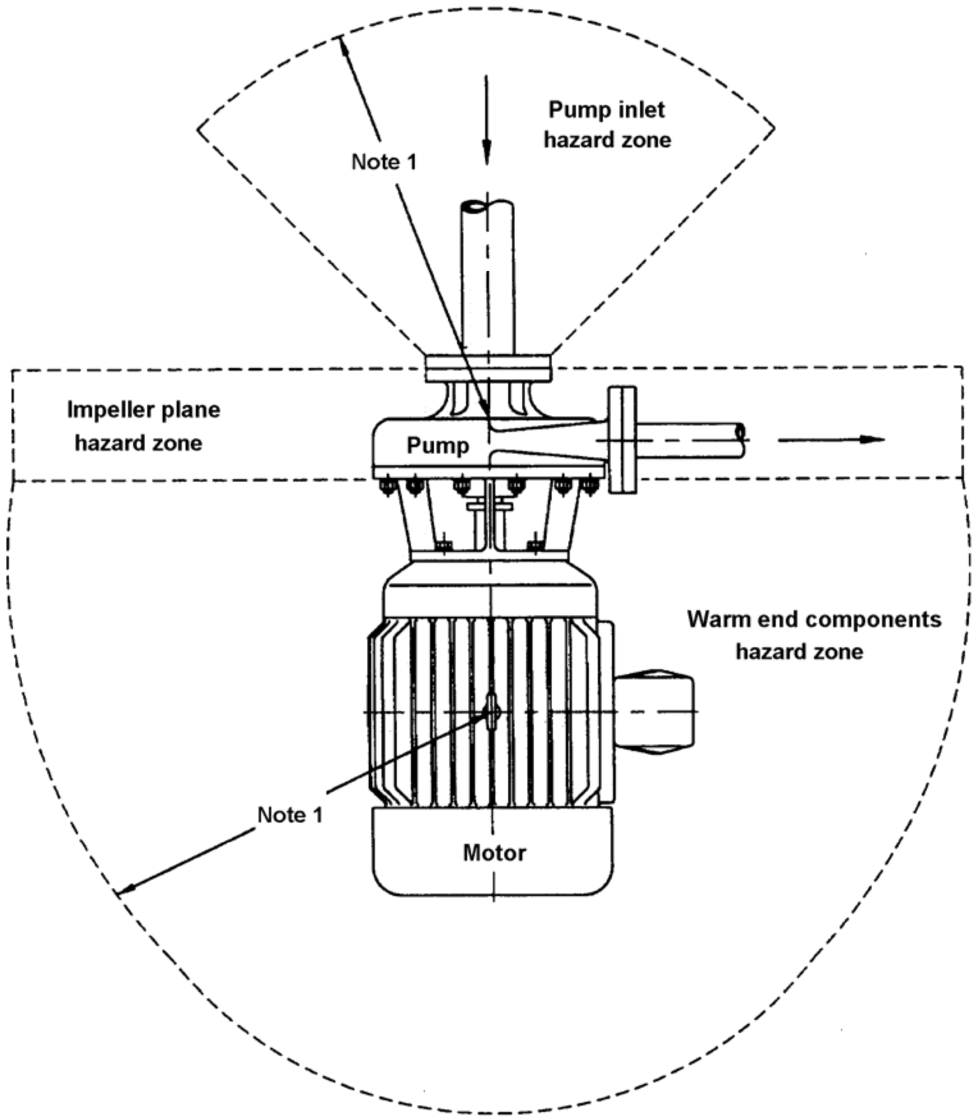
Before the change to acceptable cold-end materials, there were numerous cold-end incidents (see 4.5.2). When these incidents occurred, they usually would result in harm to personnel or equipment in either or both of two areas. The first was in the plane of rotation of the impeller and the second was in the area around the pump inlet. These areas, shown in Figure 2, were called hazard zones or areas. They were assumed to extend either to the barrier if one was provided or to a prescribed distance from the pump. That distance was arbitrarily set at varying intervals by different companies. The use of 15 ft (4.6 m) was a commonly used distance. Since the change to acceptable cold-end materials, there have been no reported cold-end incidents that have resulted in personnel injury or damage to surrounding equipment in these areas.

6.2.2 Recent experience

Incidents since the material change have occurred in the warm-end components such as motors or speed increasers of horizontal pumps. These incidents resulted in potential danger to equipment or personnel in an area behind or to the side of the motor or speed increaser (see Figure 2). Historically, warm-end incidents have not occurred in vertical pumps.

6.2.3 New definition for hazard zones

The new definition for hazard zones requires several sentences and clarifications. First, for definition purposes, there is no hazard zone if the recommended materials are used and either purging (see 6.1.1.1) or oxygen-compatible lubricants (see 6.1.1.4) are incorporated in the pump design and the methods in the rest of section 6.1 are followed. If purging or oxygen-compatible lubricants are not specified, then a hazard zone is considered to exist during pump operation as shown in Figure 2. The distances to which this hazard zone extends from the pump shall be defined by qualified technical personnel designing the system. This distance cannot be easily defined and differs between companies and between installations. Some companies have used 15 ft (4.6 m) while others have used 30 ft (9.1 m). Some companies use risk assessment techniques to establish the extent of the hazard zone. It should be recognized that some of these distances were established during the time when cold-end incidents were the primary concern. Warm-end incidents have occurred where motor parts were thrown or could have travelled over 100 ft (30.5 m). For this reason and because of the limited amount of data, the caution in 6.1.1.3 is stressed. If a barrier is used, the hazard zone is considered to end at the barrier (see 6.3). It should be noted that hazard zone is a term defined above. Even if a hazard zone does not apply, it should be assumed that a hazard can exist.



NOTES

1 The radius of the hazard zone shall be a minimum of 15 ft. A larger radius may be applied depending on the user's experience and design policy

2 If a barrier is provided, the hazard zone is considered to end at the barrier.

3 This drawing does not depict all possible pump orientations or configurations. It is intended to depict the hazard zones.

Figure 2—Liquid oxygen pump hazard zones

6.2.4 Entry into a hazard zone

No one shall be allowed into a hazard zone while the pump is in operation, and signs to that effect shall be posted. Even if the installation is such that a defined hazard zone does not apply, prudent design and operation methods should be followed that minimize the time necessary for personnel to be near an operating pump. Also, to reduce the possibility of consequential damage, other equipment shall not be located nearby.

6.2.5 Special situations

The defined uses of a hazard zone, the use of a barrier, or both are based on current common practice when all other specifics meet good safe practices such as those defined herein. Good engineering judgment still shall be used to evaluate each installation to determine if special situations exist that warrant extending or reconfiguring hazard zones, using barriers in areas not defined as hazard zones in this guideline, or taking other additional safety precautions. Some, but not all, of the possible situations where special precautions might be taken are:

- New unproven pump designs, applications, or installations;
- Higher than normal flows, pressures, or speed;
- Any non-conformance with normal oxygen pump safe practices such as those defined herein. This especially applies to the use of any different materials;
- Pumps with reservoirs of hydrocarbon lubricants in close proximity to the pump's oxygen-wetted area that do not use proven buffering or separating systems. For example, this could include gearbox-driven pumps with built-in reservoirs;
- The normally more rigorous service of pumps in continuous cooldown or continuous operation, or which could be in continuous service at some time in their life unless proven by operating experience; and
- Areas where maintenance or other activities requiring personnel to be in close proximity to pump system piping/components/valves that can be in (or put into) service and that can pose additional risk during events such as a pump being started.

6.3 Barriers

6.3.1 General

If the decision required in 6.1.1.1 has been made to use a barrier, the following guidelines apply.

6.3.2 Definition

A barrier or shield is a device that provides physical protection to people or equipment from fire and shrapnel, which could result from a cold-end or warm-end incident in a pump system. Its main purpose is to reduce the distance from the pump within which a person or object can operate safely in the event of an incident. It reduces the dimension of the hazard zone and provides protection during startup and operation. On sides where barriers are not required to protect operating or maintenance personnel or equipment, a hazard zone is considered to exist and shall meet the requirements of 6.2.3 and Figure 2.

6.3.3 Design

A barrier can be reinforced concrete or equivalent, low-carbon steel plate, or other suitable material. It shall be structurally designed to withstand the forces resulting from pressure release, possible flame impingement, and flying parts or debris. The barrier should be dimensioned to protect personnel involved in the pump operation, in maintenance on adjacent equipment, or individuals working in or passing through what would be the pump hazard area. The barrier shall not be installed too close to the pumps or in a fashion that restricts air circulation around the pump or that concentrates leaking oxygen. Its design shall also allow non-operating pump inspection including rotation check and maintenance. For "pit-mounted" or coldbox mounted cold ends, the containment enclosure can be considered the cold-end barrier; however, the warm end should be reviewed (see 6.1.1).

6.3.4 Accessory equipment

Manual valves that must be opened or closed while the pump is operating shall be located outside the barrier or positioned so the valve stem protrudes through the barrier, minimizing personnel exposure during pump operation. All devices requiring manipulation or observation while the pump is running shall be located so the operator is protected by the barrier while performing these duties. This includes but is not limited to the cooldown valve, start/stop buttons, pressure gauges, pressure switches, and the discharge valve.

6.4 Layout

6.4.1 Pump environment

The area around a pump shall be carefully designed to promote oxygen safety. Accessibility is required for removal or maintenance of cryogenic pumps.

Good ventilation is required in the immediate vicinity to dilute the concentration of oxygen and prevent accumulation in low points or quiescent areas near the pump if there is a leak. Where a cold end is installed in a containment enclosure, i.e., coldbox or pit mounted, and has flanged and or screwed connections within the enclosure, the user should consider monitoring for the presence of leaking oxygen.

There should be no combustible material stored or in use within 15 ft (4.6 m) of any oxygen pump other than lubricants in use for the pump drive units. The area within a 15 ft (4.6 m) radius of a pump shall be kept free of debris at all times. There should be no trenches, pits, or drains within 15 ft (4.6 m) of a pump with the exception of drains designed to divert spillage from the storage tank to safe areas. There should be no electrical cables within a 15 ft (4.6 m) radius (including the region above an oxygen pump) other than for the pump instrumentation or the pump motor.

Design and layout of other plant piping shall consider the possible impact on such piping if an incident occurs. Both fire and shrapnel shall be considered as possible consequences of an incident. The design shall prevent penetration or failure of piping associated with high pressure systems or systems with large volume storage (gas or liquid) resulting from a pump incident. This shall be done by keeping such piping (pump inlet and discharge piping excepted) a safe distance from the pump when not prevented by good hydraulic design or otherwise protecting the piping with barriers or shields. Piping in close proximity also shall be protected from the effects of cryogenic liquid contact by using suitable materials for low temperature service or by adequate shielding.

The ground surface where oxygen can spill shall be of inorganic material compatible with liquid oxygen. Asphalt and tar-based substances can become explosive when saturated with oxygen. Where concrete is used as a base for any cryogenic pump installation, care should be taken to avoid spillage or impingement of cold liquid or gases since this will break up concrete. Oxygen-compatible expansion joint material and caulking should be used in this area.

The designer should give consideration in design and layout of the pump containment (supporting structures) so that the structural integrity is not compromised if cryogenic liquid leaks from the pump or pump system components.

6.4.2 Location of the start button

There is some evidence that risk is greater during startup. Therefore, the local start button, if provided, should be at least 15 ft (4.6 m) from the pump and not be in an area directly behind the motor or directly perpendicular to the housing. If this cannot be done, a barrier should be provided behind which personnel can stand when the start button is used.

6.4.3 Seal leak detection

If visual inspection is to be relied on for leak determination, the layout shall provide that such observations can be made safely and that corrective measures can be taken without hazard to personnel or adjacent equipment. When the pump is located remotely, is inaccessible for visual inspection, or is operated automatically, a detector should be provided (see 7.2.1.2)

6.5 Pipework

6.5.1 Suction pipework

All piping should be attached to the pump so the manufacturer's recommended flange loads are not exceeded when at cryogenic operating or ambient conditions. Suction piping should be as short and straight as possible with a minimum number of bends and should be designed to ensure that the required net positive suction head (NPSH) is maintained at low liquid levels and at high and low flows.

6.5.2 Thermal relief valve

Any part of the system in which liquid can be trapped by valves shall be provided with a suitable relief device so fitted that the valve body is not frosted under normal operating conditions.

6.5.3 Vents and drains

Pipework shall be designed so that any liquid or gas vented or drained during cooldown or from safety valves or seal drains is diverted safely away from the operating area in a manner so that the gas or liquid does not impinge on personnel or other equipment or cause high oxygen concentrations.

6.5.4 Emergency shut-off valve

A fail-safe, actuated, emergency shut-off valve shall be installed in the suction piping of oxygen pumps connected to large volumes of oxygen [8]. The valve should be one that shuts off automatically on a pump trip or is actuated by the operator in the event of a problem. The user shall determine for what volume this valve is used, keeping in mind that the intent is to avoid large oxygen spills and resulting safety hazards.

There can be circumstances where multiple pumps having a common header can rely on a common suction shut-off valve. Examples of this are (a) where it is acceptable for both pumps to trip if one shuts down, or (b) where pumps are installed in parallel and only one unit is operated at a time.

The emergency shut-off valve, unless internal to a storage tank, shall be located between the oxygen volume and both the suction filter and the elbow closest to the pump inlet. If it is installed close enough to the pump so the valve could be rendered inoperative by fire or flying shrapnel as a result of either a cold-end or warm-end incident, it shall be shielded by a barrier.

6.5.5 Manual isolation valve

There should be a manual isolation valve for storage tanks between the tank and any actuated emergency shut-off valve so that the emergency valve can be removed for maintenance [8]. Manual isolation valves such as suction, discharge, and recirculation valves should be used where necessary to isolate a pump from the piping system.

6.5.6 Inlet filter

A removable strainer/filter shall always be used to prevent particles from entering the pump. Ideally it would only permit the passage of a particle smaller than the smallest design gap between major rotating and stationary parts of the pump. Labyrinth shaft seals, internal bearings, and impeller-to-body and inducer-to-body sealing clearances may be excluded from this requirement due to the small size of their clearances in some pump designs. However, selected mesh size shall carefully trade off pressure drop and filtration considerations. Commonly used filter sizes vary greatly (10 mesh to 100 mesh). The filter shall be robustly constructed having the fine mesh filtration material adequately supported. The filter shall be manufactured from suitable materials. The wire mesh should be a nickel-copper alloy but stainless steel is also acceptable. When stainless steel is used, a risk assessment shall be performed to confirm that the possible ignition sources under the actual pump conditions will not result in the stainless steel igniting. Backup plates are typically stainless steel or nickel-copper alloy.

6.5.7 Pipe insulation

Piping thermal insulation shall be compatible for oxygen service.

6.5.8 Discharge check valve

A check valve shall be installed in the oxygen pump discharge header *downstream of the first elbow*. The installation should ensure that the check valve cannot be rendered inoperative by a fire or flying shrapnel as a result of either a cold-end or warm-end incident.

6.5.9 Discharge isolation valve

A manual or automatic valve should be located downstream of the discharge check valve.

6.6 Additional considerations

6.6.1 Liquid storage

While outside the scope of this document, normal liquid storage safety requirements shall be observed in accordance with relevant standards and other CGA documents. Some of these standards are listed in the references section.

6.6.2 Vehicle access and parking

The passage of vehicles within 15 ft (4.6 m) of operating oxygen pumps or within hazard zones if applicable should be avoided; parking within this area shall be prohibited except for trailers that are to be filled. The 15 ft (4.6 m) limitation is based only on common practice.

7 Controls and instrumentation

7.1 General

Liquid oxygen pump operating controls should be provided consistent with good design practices, which apply for all cryogenic, centrifugal pumps. Detailed liquid oxygen pump controls vary since the system can be attended or unattended and the pump start sequence can be manual or automatic. All pump controls including a start/stop device should be located so that personnel are not required to enter any hazard zone as defined in 6.2.3 to operate the pump. Control devices that cannot be located outside of a hazard zone and provide critical control functions should be shielded from a pump cold-end or warm-end energy release. Each liquid oxygen pump system shall include a means of isolating the pump suction as outlined in 6.5.4 and 6.5.5.

7.2 Controls

7.2.1 Controls, hardware, and operator action

In addition to normal cryogenic controls, the following controls, hardware, or operator actions are provided and should be considered for shutting down the pump to minimize damage and hazardous conditions.

7.2.1.1 High pump discharge pressure

Discharge pressure indication shall be provided. A means of limiting the discharge pressure developed by the pump should be provided if the pumping system can develop a discharge pressure greater than the system's maximum allowable working pressure (MAWP). This device shall be installed in addition to a pressure relief valve set at the system's controlling component MAWP rating. A high pressure shut-down valve or a controlling bypass valve are examples of such devices.

7.2.1.2 Pump seal leak

A means of detecting a seal leak shall be provided. A number of methods are available including visual inspection. Pumps that are attended during operation should be visually inspected without entering a hazard zone for seal leaks at each pump start and at regular intervals based on maintenance history. Unattended pumps and pumps that cannot be inspected without entering a hazard zone should have a thermal or equivalent device that automatically detects a seal leak, sounds an alarm, and shuts down and isolates the pump.

7.2.1.3 Loss of prime detection

Operating a pump in a loss of prime condition can result in premature seal failures and even catastrophic events. A means of detecting and shutting down the pump on a loss of pump prime condition shall be provided. For attended pumps, this could be the operator. This system protects the pump from abnormal pump operations such as cavitation, operating the pump without liquid, or downstream piping breaks and ensures the pump is operated within the specified equipment limits. Commonly used methods include monitoring of discharge pressure, differential pressure, flow measurement, or motor low-amp. Suction pressure taps should be installed downstream of any valve or strainer and upstream of the pump. Pump discharge pressure taps shall be installed downstream of the discharge and prior to any isolation valves or check valves. A procedure may have to be developed to temporarily bypass the loss of prime detection system for pump starting. The setting for pressure, flow, or motor low-amp is the responsibility of the system designer and shall be based on the pump's performance curve characteristics.

7.2.1.4 Excess flow detection

A means of detecting excess pump flow should be incorporated into the system design. Pumps can be damaged due to forces not accounted for in the equipment design when operating at flow rates exceeding the intended design. The NPSH required by a centrifugal pump increases with flow. At excess flow the NPSH available might not be sufficient to prevent severe cavitation. It may also be necessary, depending on the system's hydraulic design, to install a pump flow limiting device such as a control valve or an orifice plate. The control devices outlined in 7.2.1.3 can be incorporated into a system design that can provide this protection.

7.2.2 Variable speed drives

Good design practices should be followed by the designer on pumps equipped with variable frequency drives, so the pump and associated system components are adequately protected in the event of overspeed. Control as described in 7.2.1.1 as well as a properly sized pressure relief valve shall be provided.

7.2.3 Emergency stop button(s)

An emergency stop button station(s) shall be mounted at a location(s) that operating and maintenance personnel would normally pass through when exiting the pump installation during an emergency. The emergency stop button station(s) shall be clearly labelled and identified for the system it operates. The emergency stop button shall stop the pump and immediately activate any automatic isolation valves.

7.3 Maintenance and analytical tools

Individual users should consider additional instrumentation to detect the need for maintenance, analyze pump performance, or for specialized pumping applications. Commonly used instrumentation includes:

- pump suction pressure indication;
- pump suction strainer pressure drop;
- pump hour meter for elapsed running time;
- running light to indicate pump in operation; and
- vibration devices to detect abnormal pump operation.

8 Operation and maintenance

8.1 Warning signs

8.1.1 Hazard zone sign

If a hazard zone is the primary installation safety method used (see 6.1 and 6.2), warning signs shall be placed in conspicuous locations advising all personnel that WHILE THE LIQUID OXYGEN PUMP IS IN OPERATION,

ACCESS TO DESIGNATED HAZARD ZONES IS PROHIBITED. Operator access to an operating pump should be restricted to areas outside the designated hazard zone.

8.1.2 Oxygen pump sign

A sign should be located close to a pump to alert all personnel that the pump is an OXYGEN PUMP.

8.2 Training

All pump operators and maintenance personnel shall receive appropriate training such as pump fundamentals (hydraulic and mechanical); specific startup, operation, and maintenance procedures; anomaly detection (seal leakage, cavitation, unusual bearing/drive noises); oxygen cleaning; and safety requirements for handling cryogenic liquid oxygen.

8.3 Startup and operation

8.3.1 Written procedures

Written instructions that define startup, operating, shutdown, and emergency procedures shall be developed for each liquid oxygen pump and shall be kept in the plant files. A copy of these instructions shall be reviewed with and made available to the pump operators. Instructions shall be periodically reviewed and updated as required, and changes shall be reviewed with the appropriate operators. Instructions shall include, but not be limited to, details pertaining to the following items:

- Methods needed to determine that proper cooldown is achieved without freezing pump/motor bearing lubricant;
- Precautions to be followed to provide adequate liquid subcooling at the pump inlet to prevent cavitation such as minimum tank liquid level/pressure;
- Appropriate position of all piping system valves for each mode of operation (cooldown, startup, operation, shutdown, etc.);
- The method used to check the pump shaft for freedom of rotation (warm and cold condition) and the frequency of these checks. All freedom of rotation checks shall be performed only after the pump motor has been properly isolated, electronically locked out, and tagged. Typical methods used to check for freedom of rotation are turning the pump shaft by hand, removing the end bell of the motor and turning the pump motor fan or shaft, using a wrench on the pump shaft flats, and opening the beltbox and carefully using force on the belts. It is recommended that the shaft freedom of rotation be checked after maintenance or extended shutdowns;
- Verification of pump direction of rotation on any unit that might have had motor wiring phase changes. Wiring phase changes are possible after any motor/pump maintenance requiring lead disconnection at the motor or motor control centre;
- Permissible process operating limits to preclude pump damage. For example, permissible flow or discharge pressure ranges to prevent cavitation and maximum speed for variable speed drives;
- A list of pump normal operating conditions such as pump flow rate, seal 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 such as seal leakage or abnormal noises are detected.

8.3.2 Pump cooldown

The following should be considered for pumps on continuous or prolonged cooldown:

- A means of preventing the pump bearing lubricant from freezing should be used. Pump design considerations to prevent the bearing lubricant from freezing are discussed in 5.5.2 and 5.5.3; and
- Some pumping systems have the potential to accumulate hazardous dissolved hydrocarbons at low points in the system when on continuous cooldown. A pump should be regularly flushed or a routine sampling/analysis programme should be instituted to detect any hydrocarbons at the system low points. Any concentration increase in hydrocarbons detected requires that the system be drained.

8.3.3 Ice bridging

A pump designed to prevent bridging of ice from the cold end over the distance piece to the warm end is preferred to prevent “tunnelling” of oxygen from a leaking seal into the warm end. However, if the pump develops a significant ice buildup, other methods shall be used to reduce the size of the ice ball. Examples are stopping and defrosting the pump using hot gas or steam to melt the ice or physically breaking the ice with a bronze hammer. When removing the ice, care shall be taken to prevent overpressure or damage to the pump.

8.4 Condition assessment

8.4.1 Pump assessment

Pump mechanical and hydraulic performance shall be periodically reviewed. It is recommended that the observations or at least details of abnormalities be recorded for further action or reference. As a minimum these checks shall include:

- analysis of operating data;
- manual rotation of pump shaft to assess bearing condition or mechanical rubs;
- oil level/lubrication replenishment as appropriate; and
- seal leakage.

8.4.2 Condition assessment frequency

The frequency of these reviews depends upon extent of use, manufacturer’s recommendations, and actual operating experience.

8.5 Maintenance and repair

8.5.1 Maintenance programme

A maintenance programme integrating the pump manufacturer’s recommendations and the users’ experience shall be developed.

8.5.2 Repair procedures

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

8.5.3 Parts

Parts approved for oxygen service that are properly inspected and cleaned shall be used. Refer to CGA G-4.1 [2].

8.5.4 Personnel qualifications

All maintenance shall be performed by individuals qualified in oxygen pump repair as well as oxygen cleaning procedures.

8.5.5 Records

A detailed chronological record of all pump maintenance and repairs should be kept. These records are useful in identifying and diagnosing chronic problems.

8.6 Filters/screens

8.6.1 Filter/screen cleaning

Pump inlet filters/screens shall be periodically inspected and cleaned.

8.6.2 Filter/screen cleaning frequency

Cleaning frequency is dependent upon the level of inlet piping contamination and is especially critical following either system modifications or repairs. The following should be considered to determine cleaning frequency:

- After pump system commissioning or system modification/repair, the pump filter/screen should be inspected and cleaned within approximately 100 hours of operation;
- Time between inspections may be increased based upon the improving level of system cleanliness or differential pressure indication or both; and
- Pump replacement or removal for maintenance/repair provides a good opportunity for inspection. Filters/screens should always be inspected at each pump replacement regardless of the time since prior cleaning.

9 References

Unless otherwise specified, the latest edition shall apply.

[1] CGA P-8, *Safe Practices Guide for Air Separation Plants*, Compressed Gas Association, Inc., 4221 Walney Rd., 5th Floor, Chantilly, VA 20151. www.cganet.com

[2] CGA G-4.1, *Cleaning Equipment for Oxygen Service*, Compressed Gas Association, Inc., 4221 Walney Rd., 5th Floor, Chantilly, VA 20151. www.cganet.com

[3] CGA G-4, *Oxygen*, Compressed Gas Association, Inc., 4221 Walney Rd., 5th Floor, Chantilly, VA 20151. www.cganet.com

[4] ASTM G94*, Standard Guide for Evaluating Metals for Oxygen Service*, ASTM International, 100 Barr Harbour Dr., West Conshohocken, PA 19428. www.astm.org

[5] ASTM D2512*, Standard Test Method for Compatibility of Materials with Liquid Oxygen (Impact Sensitivity Threshold and Pass-Fail Techniques),* ASTM International, 100 Barr Harbour Dr., West Conshohocken, PA 19428. www.astm.org

[6] CGA P-11, *Metric Practice Guide for the Compressed Gas Industry*, Compressed Gas Association, Inc., 4221 Walney Rd., 5th Floor, Chantilly, VA 20151. www.cganet.com

[7] ASTM G63*, Standard Guide for Evaluating Non-metallic Materials for Oxygen Service*, ASTM International, 100 Barr Harbour Dr., West Conshohocken, PA 19428. www.astm.org

[8] CGA P-25, *Guide for Flat-Bottomed LOX/LIN/LAR Storage Tank Systems*, Compressed Gas Association, Inc., 4221 Walney Rd., 5th Floor, Chantilly, VA 20151. www.cganet.com

[9] AIGA 056/08, *Safe practices guide for Air Separation Plants*, Asia Industrial Gases Association, www.asiaiga.org

[10] AIGA 012/04, *Cleaning of equipment for oxygen service ,* Asia Industrial Gases Association, www.asiaiga.org

[11] AIGA 005/04, *Fire hazards of oxygen and oxygen enriched atmospheres,* Asia Industrial Gases Association, www.asiaiga.org