# CENTRIFUGAL COMPRESSORS FOR OXYGEN SERVICE

## Doc 27/23/REV

Revision of Doc 27/12


***EUROPEAN INDUSTRIAL GASES ASSOCIATION AISBL***

AVENUE DE L'ASTRONOMIE 30 • B – 1210 BRUSSELS
Tel: +32 2 217 70 98
E-mail: info@eiga.eu • Internet: www.eiga.eu

# CENTRIFUGAL COMPRESSORS FOR OXYGEN SERVICE

Prepared by WG-3 Atmospheric Gases

As part of a programme of harmonisation of industry standards, the European Industrial Gases Association (EIGA) has published EIGA Doc 27, Centrifugal Compressors for Oxygen Service. This publication was jointly produced by members of the International Harmonisation Council. This publication is intended as an international harmonised publication for the worldwide use and application by all members of the International Harmonisation Council whose members include the Asia Industrial Gases Association (AIGA), Compressed Gas Association (CGA), European Industrial Gases Association (EIGA), and Japan Industrial and Medical Gases Association (JIMGA). Regional editions have the same technical content as the EIGA edition, however, there are editorial changes primarily in formatting, units used and spelling. Regional regulatory requirements are those that apply to Europe



**EUROPEAN INDUSTRIAL GASES ASSOCIATION AISBL**
Avenue de l'Astronomie 30 B 1210 Brussels Tel +32 2 217 70 98
E-mail: info@eiga.eu Internet: www.eiga.eu

**Table of Contents**


1 Introduction ........ 1

2 Scope and purpose ........ 1

2.1 Management of hazards ........ 1
2.2 Design of the compressor system ........ 2
2.3 Cleaning, preservation, and inspection ........ 2
2.4 Erection, testing, and commissioning ........ 2
2.5 Operation ........ 2
2.6 Maintenance ........ 2
2.7 Other specifications ........ 2
2.8 Speed ........ 3

3 Definitions ........ 3

3.1 Publication terminology ........ 3
3.2 Technical definitions ........ 3

4 Compressor design ........ 4

4.1 Design criteria ........ 4
4.2 General materials ........ 4
4.3 Compressor parts ........ 5
4.4 Rotor dynamic analysis, verification tests, and data to be provided ........ 12
4.5 Balancing and vibration ........ 12
4.6 Insulation and grounding ........ 13

5 Process pipework ........ 14

5.1 Extent ........ 14
5.2 Connections ........ 14
5.3 Welding ........ 14
5.4 Prefabrication ........ 14
5.5 Vents to atmosphere ........ 14
5.6 Special piping ........ 15
5.7 Bellows ........ 15
5.8 Gaskets ........ 15
5.9 Acoustic and thermal insulation ........ 15
5.10 Silencers ........ 15
5.11 Vaned elbows ........ 16
5.12 Main suction filter ........ 16

6 Manual valves ........ 16

6.1 Manually operated main isolation valves ........ 16
6.2 Manual valves that form part of the oxygen compressor envelope ........ 16

7 Intercoolers and aftercoolers ........ 17

7.1 Scope of supply ........ 17
7.2 Types of cooler ........ 17
7.3 Vents and drains ........ 18

8 Lubricating oil system ........ 19

8.1 General ........ 19
8.2 Oil pumps ........ 19
8.3 Filter ........ 19
8.4 Oil heater ........ 19
8.5 Oil vapour extractor system ........ 19
8.6 Oil tank ........ 20
8.7 Control ........ 20

9 Controls and instrumentation ........ 20

9.1 General ........ 20

9.2 Control system ..... 20
9.3 Anti-surge system ..... 21
9.4 High oxygen temperature protection ..... 23
9.5 High bearing temperature protection ..... 23
9.6 Overspeed protection ..... 23
9.7 Vibration and shaft position ..... 24
9.8 Safety shutdown system valves ..... 24
9.9 Oxygen humidity ..... 25

10 Seal gas system ..... 27

10.1 Compressor seal gas system ..... 27
10.2 Bearing seal gas system ..... 27
10.3 Schematic diagrams ..... 27

11 Inspection and shipping ..... 32

11.1 Introduction ..... 32
11.2 Responsibility ..... 32
11.3 Inspection and cleanliness standards ..... 32
11.4 Preservation of oxygen cleanliness during shipping and storage ..... 32

12 Compressor installation ..... 33

12.1 Hazard area ..... 33
12.2 Enclosure of the hazard area by a safety barrier ..... 33
12.3 Access to the hazard area ..... 34
12.4 Equipment location ..... 34
12.5 Safety barrier ..... 35
12.6 Safety barrier miscellaneous design features ..... 39
12.7 Location ..... 40
12.8 Fire protection and precautions ..... 40
12.9 Protection of personnel ..... 41

13 Erection and commissioning ..... 41

13.1 Erection ..... 41
13.2 Testing and commissioning ..... 42
13.3 Commissioning on oxygen ..... 45

14 Operation ..... 46

14.1 General ..... 46
14.2 Combustible matter ..... 46
14.3 Machine rubs ..... 46
14.4 Rotor/bearing instability ..... 46
14.5 Machine vibrations ..... 46
14.6 Leaking cooler tubes ..... 46
14.7 Gas leakage hazard ..... 46
14.8 Compressor surge ..... 46
14.9 Machine protection systems ..... 46
14.10 Operational inspections ..... 46
14.11 Responsibility transfer documentation ..... 47
14.12 Qualifications and training for operating personnel ..... 47
14.13 Hazard area ..... 47
14.14 Fire drills ..... 47
14.15 Emergency purge and vent systems ..... 47
14.16 Record of machine operation ..... 47
14.17 Tripping devices ..... 47
14.18 Interlock systems ..... 47
14.19 Oil filters ..... 48
14.20 Startup procedures ..... 48

15 Maintenance ..... 48

15.1 General ..... 48

15.2 Cleanliness during maintenance ........ 49
15.3 Rotor checks ........ 50
15.4 Startup after maintenance ........ 50
15.5 Spare parts ........ 50

16 Instruction manual ........ 50

16.1 General ........ 50
16.2 List of minimum information ........ 50
16.3 Additional Information ........ 51

17 References ........ 51

**Amendments to 27/12**

| Section | Change |
|---|---|
| 2 | Add 1st paragraph |
| 3 | New section 3 added |
| 4.2.3 | Paragraph was amended |
| 4.3.3 | Paragraph was amended |
| 7.2.4 | New paragraph added |
| 8.5 | In Doc 27 REV, a last sentence was added to this paragraph |
| 9.1 | New paragraph added |
| 9.4 | New paragraph added |
| 10.3 | Schematic diagrams added |
| 12.2 | New paragraph added |
| 12.3 | New paragraph added |
| 12.5.9 | Schematic diagram added |
| 14.10 | Paragraph was amended |
| 14.16 | Paragraph was amended |
| 14.20 | Paragraph was amended |
| 15.1.2 | New paragraph added |

NOTE—Technical changes from the previous edition are underlined

## 1 Introduction

This publication has made a significant contribution to the safe compression of oxygen primarily because the manufacturers and users have shared their philosophies and experiences. It is recognised by the Working Group members that the feedback of operating experiences makes a powerful contribution to safe operation and design.

Oxygen compression represents a risk in that the compressor can burn violently. This publication defines design and operating parameters for centrifugal oxygen compressors. Compliance with this publication can reduce the likelihood of, and the hazards arising from, a fire in a compressor to a level equal to or less than those commonly accepted in the air separation industry.

The publication requires that all those who build and operate centrifugal oxygen compressors specified to comply with this publication should contribute towards it by fully reporting the circumstances surrounding oxygen fires. For the purpose of safe operation of the compressor and its auxiliaries, the user and the manufacturer shall establish full agreement on the possible and expected modes of compressor operation (for example, specified operating points, normal operating range, startup and shutdown, etc.)

## 2 Scope and purpose

This publication applies to single shaft horizontally split casing and vertically split casing (barrel) type compressors and integrally geared compressors. Operating experience exists in compressors up to 71 000 $Nm^3$/hr (2 700 000 scfh) at pressures up to 8.5 MPa (1230 psig) for single shaft compressors and up to 4.5 MPa (650 psig) for integrally geared compressors with oxygen purity of 90% or greater and with maximum 10 ppm water (volume basis).[1, 2]

The use of axial compressors in oxygen service is not covered by this publication.

The purpose of this publication is to provide guidance on the design, manufacture, installation, operation, and maintenance of centrifugal oxygen compressors, thereby safeguarding personnel and equipment. Fire in an oxygen compressor can be caused by a variety of reasons, which include mechanical deterioration resulting in excessive vibration and/or loss of running clearances within the compressor, ingress of oil (for example, through the seal system), foreign bodies passing through the machine, and surge.

An oxygen compressor shall be provided with a safety support system that shall minimise the development of a potentially dangerous operating condition. In the event of an incident on the compressor that results in combustion of the materials of construction, the safety systems shall be designed to minimise the effect of the fire.

The safe and reliable compression of oxygen using centrifugal compressors can only be achieved by the successful combination of many factors. This publication identifies and addresses the following factors.

### 2.1 Management of hazards

- identification of the hazard;

---

[1] psi, bar, and kPa/MPa shall indicate gauge pressure unless otherwise noted as (psia; bar, abs; and kPa/MPa, abs) for absolute pressure or (psid; bar, dif; and kPa/MPa dif) for differential pressure. All kPa values are rounded off per
CGA P-11, *Guideline for Metric Practice in the Compressed Gas Industry* [1].
[2] References are shown by bracketed numbers and are listed in order of appearance in the reference section.

- hazard area, safety barriers, and enclosures;
- location of the compressor; and
- emergency procedures.

## 2.2 Design of the compressor system

- robust and well proven compressor design;
- stable rotor system;
- safe materials in critical areas;
- comprehensive instrumentation;
- safety shutdown system;
- auxiliary system; and
- control system including surge protection.

## 2.3 Cleaning, preservation, and inspection

- correct and properly enforced procedures carried out by trained personnel.

## 2.4 Erection, testing, and commissioning

- trained erection personnel; and
- comprehensive testing programme to verify the design.

## 2.5 Operation

- trained personnel; and
- correct procedures.

## 2.6 Maintenance

- condition monitoring;
- planned preventive maintenance; and
- trained personnel.

## 2.7 Other specifications

For more information, see EIGA Doc 147, *Safe Practices Guide for Cryogenic Air Separation Plants* [2].

In case of conflict between this publication and the user's specification, the information included in the order shall be the more stringent. The supply shall be in conformity with the rules of the country of the user and/or of the manufacturer.

See also Section 17, References.

### 2.8 Speed

Speeds shall be according to 1.5 of API Standard 617, *Axial and Centrifugal Compressors and Expander-compressors*, for example, rated speed, normal speed, maximum continuous speed as well as trip speed [3].

## 3 Definitions

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

### 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 a procedure is recommended.

#### 3.1.3 May

Indicates that the procedure is optional.

#### 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 Dry, oil-free, air or nitrogen

Air or nitrogen with a dew point of –40 °F (–40 °C) or less and an oil content of 0.5 mg/$m^3$ or less.

Hazard area
Area where an incident is most likely to occur and as a consequence is capable of causing danger and/or injury to personnel.

NOTE—The term hazard area is not to be confused with electrical hazardous area classification.

#### 3.2.2 Maximum operating temperature

Highest temperature that can be measured anywhere in the main gas stream under the most severe operating conditions.

#### 3.2.3 Seal gas

Ambient temperature dry (dew point of less than –40 °C [–40 °F]), oil-free, particle-free, and carbon dioxide-free (less than 3 ppm) nitrogen, argon, or air.

NOTE—Also known as buffer gas.

# 4 Compressor design

## 4.1 Design criteria

### 4.1.1 Possible causes of an oxygen compressor fire

It is normally very difficult to precisely ascertain the cause of a fire in an oxygen compressor because the material at and around the ignition site are completely burnt up. Therefore, during the design, manufacture, and maintenance of centrifugal oxygen compressors both active and passive safety measures shall be taken to guard against all of the causes of ignition.

Causes of ignition, sources of friction, or foreign material can include:

- mechanical rub—improper design, clearances, vibration, operating pressure, assembly or maintenance errors, bearing failure, thrust, alignment, improper intercooling, transient instability such as startup, shutdown, or process upset (can include shock and surge);
- large debris impact—screen/filter failure or improper mesh size, weld debris or slag, friction/shock, maintenance debris, shot, sand;
- debris—screens, weld debris or slag, oxides such as rust, maintenance debris, shot, sand;
- contamination—oil, assembly grease, improper design of bearings/seals and/or associated vents and drains, deposits from cleaning agents;
- resonance—debris in dead areas;
- non-metallic materials with a low autoignition temperature; and
- long-term deterioration of components, key tolerances, etc.

### 4.1.2 Machine configuration

Compared with single shaft compressors with closed wheels, integral gear compressors can have open and/or closed wheels and have the following design differences:

- Greater number of seals letting down to atmospheric pressure and in close proximity to the gearbox;
- More complex assembly;
- Stable rotor dynamic design of integrally geared compressors is more difficult to achieve than in single shaft compressors, in general. Therefore, additional consideration in the rotor dynamic design shall be taken to provide acceptable rotor stability in oxygen service; and
- Greater sensitivity to upset condition such as surge.

## 4.2 General materials

### 4.2.1 Construction materials

When selecting materials of construction for an oxygen compressor, components that come into contact with oxygen shall have oxygen compatibility. Materials that fulfil these criteria usually have the following properties:

- high ignition temperature;
- high thermal conductivity;

- high specific heat; and
- low heat of combustion.

#### 4.2.2 Use of aluminium

Because of its high heat of combustion, the use of aluminium or alloys containing aluminium shall be limited for oxygen wetted or potentially oxygen wetted parts. Aluminium will not sustain combustion at less than certain pressures and purities. The use of aluminium shall be limited to a pressure less than or equal to 0.2 MPa (29 psi) for the oxygen purity range covered by this publication.

In addition, the maximum permitted aluminium content in a copper alloy is 2.5%.

#### 4.2.3 Oxygen compatibility of non-metallic materials

Non-metallic materials shall be tested for their suitability for oxygen service. Information can be found in
M 034-1 *List of non-metallic materials compatible with oxygen* by BAM and ASTM G63, *Standard Guide for Evaluating Nonmetallic Materials for Oxygen Service* [4, 5]. This does not preclude other methods of determining compatibility such as by other independent bodies, customers, and suppliers.

### 4.3 Compressor parts

#### 4.3.1 Casings

##### 4.3.1.1 Casing allowable working pressure

Calculations shall be carried out to determine the maximum pressure that the casing can experience during operation. It shall be the highest pressure of the following options that can be reached in the casing (or subdivision of casings into chambers) multiplied by an agreed safety factor between the user and the manufacturer.

- The maximum operating pressure at the surge limit resulting from the maximum specified suction pressure at the maximum continuous operating speed. Agreed deviations from gas properties and suction temperature are to be considered;

  NOTE—In some instances a rotor stability test at greater than the maximum design operating pressure is specified. If this is the case, it should be taken into account when specifying the casing allowable working pressure;

- The maximum pressure that results from the maximum specified suction pressure and the greatest pressure rise possible with the given maximum drive power at the maximum continuous operating speed. Agreed deviations from gas properties and suction temperature are to be considered;
- The maximum equilibrium pressure reached in the compressor system under certain running or shutdown conditions; and
- If the casing pressure is limited by a safety device set to a pressure agreed between the user and manufacturer, this pressure can be used as the casing allowable working pressure. The casing may also be subdivided into chambers for calculation and testing. In this case, the maximum possible pressure in these chambers is to be used as a basis, taking into consideration the aforementioned aspects.

##### 4.3.1.2 Pressure tests

The compressor main casing or volutes shall be hydrostatically tested in the manufacturing facility with potable water at a minimum test pressure of 1.3 times the allowable working pressure of each portion of the casing. The casing allowable working pressure is defined in 4.3.1.1.

The test pressure shall be held for at least 30 minutes to permit complete examination of the casing under pressure. Casings and volutes that leak under hydrostatic test shall not be acceptable.

#### 4.3.1.3 Casing material

The following materials have proved satisfactory with regard to the criteria listed in 4.2:

- grey cast iron;
- nodular cast iron;
- high alloy steel–cast or fabricated; and
- welding of cast steel and fabricated steel casings is permitted if the execution and heat treatment are properly conducted.

#### 4.3.1.4 Casing repairs

All internal spaces of the casing should be easily accessible for cleaning and inspection. Hard soldering or metal locking repairs to cast iron casings are not permitted unless agreed between the manufacturer and the user. Minor defects in cast casings may be repaired with screwed plugs if agreed between the manufacturer and the user. This publication requires that these plugs be positively prevented from falling into the compressor. The preferred way is to use positively locked, taper plugs from the outside only. Welding repairs to grey cast iron is forbidden; however, with the permission of the user, it may be carried out on the other materials listed previously. The use of non-metallic materials for repair work is forbidden.

#### 4.3.1.5 Casing sealing material

If non-metallic materials are employed for sealing the casing, they shall be oxygen compatible and agreed by the manufacturer and the user. If used, liquid sealant shall be applied so that it does not creep or project into the inside of the machine. If required, threads shall also be sealed by materials that are compatible with oxygen.

#### 4.3.1.6 Anti-galling compound

If an anti-galling compound is to be applied to centreing fits, bolts, studs, etc., only compounds compatible with oxygen service shall be used. Compounds shall be mutually agreed between the manufacturer and the user.

#### 4.3.1.7 External forces and moments

The compressor manufacturer shall specify the nozzle displacements due to thermal movements of the compressor. It is preferred that the permissible forces and moments on each flange/nozzle to which the user has to connect are 1.85 times the values calculated in accordance with NEMA SM 23, *Steam Turbines for Mechanical Drive Service* [6]. If this is not possible, they shall be mutually agreed between the manufacturer and the user.

### 4.3.2 Diaphragms and diffusers

#### 4.3.2.1 Materials of inter-stage diaphragms and diffusers associated with closed impellers

The diaphragms shall be designed to withstand the maximum possible differential pressures. Grey cast iron and nodular cast iron have been widely used up to 5 MPa (725 psi). High alloy steel, copper alloys, nickel alloys, and copper nickel alloys are recommended greater than 5 MPa (725 psi).

#### 4.3.2.2 Materials of shrouds (diaphragms) and diffusers associated with open impellers

It is not permitted to use open impellers with shrouds made of materials less compatible with oxygen than copper alloys or nickel alloys.

#### 4.3.2.3 Diffusers—Design features

##### 4.3.2.3.1 Vaneless diffuser with spiral collector

Pressure variation around the circumference of the diffuser can be powerful enough to excite the covers and backplates of the impellers. This phenomenon becomes more pronounced at surge and at stonewall conditions and more powerful at high pressures. If the diffuser is long enough, this phenomenon is avoided. Therefore, the diffuser diameter shall be greater than 1.4 times the impeller diameter.

##### 4.3.2.3.2 Fixed diffuser vanes

- The use of fixed diffuser vanes as an integral part of the diffuser assembly in oxygen service has been proven over several years of operation. Fixed diffuser vanes can be used in oxygen service;
- The vanes are subject to strong excitation forces being close to the impeller and in an area of high velocity and changing density. Therefore, the vanes shall be subject to careful analysis to ensure that resonant modes are not excited;
- Diffuser vanes shall have no high energy excitation frequencies corresponding to multiples of the number of impeller blades and the rotating speed. The number of diffuser blades and the number of impeller blades shall have no common denominator and should preferably be prime numbers; and
- The use of vaned diffusers is not permitted unless resonance calculations have been carried out. These calculations shall be based upon test data.

##### 4.3.2.3.3 Variable diffuser vanes

Variable diffuser vanes shall not be used. Variable diffuser vanes involve very small angular movements, tight side clearances, blades with long unsupported lengths, and complex operating mechanisms. When these are combined with high excitation forces and their physical position in the compressor, they represent a considerable additional risk.

### 4.3.3 Variable inlet guide vanes

The use of variable inlet guide vanes is permitted. In normal operation, the inlet guide vane (IGV) opening or closing time should be limited to maximum 1% per second of the controller output to avoid abrupt flow change and surge.

The design of the variable inlet guide vanes shall take into account:

- Excitation due to the flow disturbances caused by the stage inlet piping;
- Excitation of the impeller;
- The design shall be so either it is physically impossible for the vanes to go to the fully shut position or, if the vanes are permitted to go to the fully shut position, there shall be sufficient flow area to prevent the vanes being overloaded and to dissipate the heat caused by windage;
- They shall be of a non-lubricated design;
- The design shall avoid the risk of oxygen leakage to the atmosphere. The use of a seal gas system is recommended; and

- Suitable materials for oxygen service that shall be resistant to impingement and high velocity of gas.

### 4.3.4 Rotating assembly

#### 4.3.4.1 Impellers

##### 4.3.4.1.1 Materials

High alloy steels (not austenitic) are the materials normally used for impellers.

##### 4.3.4.1.2 Manufacture

Impellers may be cast, forged, spark-eroded, milled, brazed, or welded. Riveted impellers shall not be used. The impellers shall be subjected to an over-speed test for 3 minutes at the speeds stated in 2.8. Following this test, the impellers shall be crack-tested and checked for dimensional changes. Two diameters on the impeller should be marked and the dimensional change for each diameter is to be found by comparing the length before and after the overspeed test. Impellers shall also be dye penetrant or magnetic particle tested. All dye and other penetrant shall be carefully removed after the test. Acceptance criteria shall be agreed between the manufacturer and the user.

#### 4.3.4.2 Open impellers for geared compressors

- Open impellers have a smaller clearance between the rotating and stationary part of the stage, which leads to an increased risk of a high speed rub. This small clearance has to be set with the compressor cold. During transient operation, particularly during startup, different parts of the compressor heat up at varying rates and there is a danger that this will cause the impeller to touch. The risk associated with this can be reduced by ensuring that the compressor is always started up using dry, oil-free, air or nitrogen and brought close to operating temperature before changing over to oxygen;
- Open impellers are normally used in an overhung configuration. The seal system required for oxygen is quite long. The result is that the amplitude of vibration of the impeller can be large when a resonant mode of the rotor is excited. The smaller impeller to stator clearances used with open impellers results in a greater risk of a high speed rub;
- Impeller stress levels permit open impellers to be run at higher tip speeds with a resultant higher rubbing velocity; and
- The blades on an open impeller are only supported at their base; therefore, there is a greater likelihood of them being excited at a resonant frequency and failing in consequence. A frequency analysis of the individual impellers is of the utmost importance. The manufacturer shall demonstrate the location of the first three natural frequencies of the impeller and that these do not correspond to known existing frequencies due to, for example, diffuser vanes.

### 4.3.5 Shafts

The shafts of centrifugal compressors shall be forged from one piece and checked for defects using ultrasonic tests. The electrical and mechanical run-outs in the planes of the vibration probes shall be reduced to 6 micron peak to peak or less during the course of the manufacturing programme.

### 4.3.6 Rotor assembly

Shaft sleeves are permissible. Components shrunk onto or fitted to the shaft shall be degreased before fitting.

For single shaft compressors, assembled rotors with shrunk on components shall be submitted to an overspeed run prior to the final rotor balance in order to release all unequal settings of components on the shaft. Whenever a rotor is rebuilt, overspeed shall be considered prior to balancing (see 4.5.1).

Thrust collars shall be machined as part of the solid shaft or positively retained using a locknut, shear ring, or grip enhancement method. The use of a simple interference fit shall not be used.

### 4.3.7 Seals

#### 4.3.7.1 Internal rotor seals

Depending on the type of compressor (single shaft or integrally geared), the internal rotor sealing has the function of keeping the amount of gas leaking between impeller outlet and impeller inlet and between adjacent stages as low as possible. Adequate clearances shall be provided between sealing tips and sealing faces, so that contact is limited to an amount agreed between the manufacturer and the user under all operating conditions. The internal seals of an oxygen compressor shall only be of the labyrinth type. The design and the choice of materials for the tips and sealing faces shall be so in the event of contact the least possible amount of heat is developed and the resulting heat is readily dissipated.

The seal assembly is usually replaceable and typically held in place using a sliding "rail" fit. In such designs, consideration should be given to avoid fretting, for example, apply hard coating to the seal locating surface.

##### 4.3.7.1.1 Rotating tips

The following materials shall be used:

- rotating tip–copper alloy or nickel alloy; and
- stationary face–silver layer bonded to a copper alloy or nickel alloy backing.

As a minimum, the thickness of the silver layer shall take into account the shaft movement that can occur in the event of:

- total bearing failure; and/or
- rotor being excited in resonance.

The silver shall be of such a thickness that the rotating tip cannot cut through the silver layer and touch the copper alloy or nickel alloy backing.

These criteria apply to both radial and axial labyrinths. It is important with this type of seal that the tips and the silver are designed in a way that ensures that the tips cut satisfactorily into the silver face.

Silver has shown itself to be a very safe material for use in seals. Experience has shown that it is safe to permit the rotating tips to cut into the stationary silver face during rotor excursions that occur during startup and surge. The amount of cut in shall be agreed between the manufacturer and the user.

For overhung impellers, for example, gear-type compressor, the benefits of a silver counter face are well established in seal design. However, a rotating labyrinth running against a silver stationary counter face can lead to violent rotor excursions in the event of rub.

##### 4.3.7.1.2 Stationary tips

The following materials shall be used:

- stationary tip–silver mounted on copper alloy or nickel alloy base; and
- rotating face–high alloy steel, copper alloy, or nickel alloy.

The stationary tip shall be of sufficient width to provide adequate strength and of sufficient height to prevent contact between the rotating shaft and the stationary copper or nickel alloy base in the event of a rotor excursion due either to a bearing failure or rotor instability. These criteria apply to both radial and axial labyrinths.

#### 4.3.7.2 Atmospheric rotor seals

##### 4.3.7.2.1 Function

The function of the atmospheric portion of the gas seal is to preclude the escape of oxygen out of the compressor along the shaft as well as the possibility of the introduction of air or oil via the seal.

The seal shall be effective during all operating conditions including standstill, startup, and rundown (see Section 10).

##### 4.3.7.2.2 Compressor atmospheric rotor seals—Labyrinth type

The atmospheric rotor seals shall be of the labyrinth type, which is the only type of seal permitted by this publication except under exceptional circumstances (see 4.3.7.2.3). With respect to design, materials, and clearances, this type of seal shall comply with 4.3.7.1.

At least three sealing chambers shall be provided. The inner chambers are connected to the suction in order to reduce the differential pressure across the seal to a minimum. The centre chamber is for venting or exhausting. The outer chamber is for the supply of seal gas.

The internal pressure of outer and centre seal chambers should be measured by providing separate measuring connections close to the seal chambers to ensure that the pressure measurement is affected as little as possible by the gas flow in the seal system. If the design of the compressor makes it impossible to fit separate measuring connections, when it is agreed between the manufacturer and the user, it is acceptable to measure the pressure away from the seal chambers provided that the pressure drop due to flow between the seal chamber and the measuring point is insignificant compared to the pressure being measured. The manufacturer shall provide pressure drop calculations at seal clearances that are four times design.

##### 4.3.7.2.3 Compressor atmospheric rotor seals—Alternative types

There are certain applications such as pipeline compressors where the use of labyrinth seals presents operating difficulties (for example, where availability of seal gas is limited). Other types of seals may be considered as agreed to between the manufacturer and the user.

#### 4.3.7.3 Bearing housing seal

#### 4.3.7.4

The function of this seal is to prevent oxygen from getting into the oil system and to prevent oil vapour escaping from the oil system. There are no oxygen compatibility or seal material requirements.

#### 4.3.7.5 Separation of rotor process gas seal and oil seals

Precautions shall be taken to avoid contamination of the process gas seals by oil and/or oil mist leakage or oxygen migration into the lubricated parts, which can lead to major safety hazards.

##### 4.3.7.5.1 Single shaft oxygen compressors

An air gap open to the atmosphere between the compressor casing and bearing housing shall be provided. This shall have an arc width at least equal to the shaft diameter and large enough to guarantee atmospheric pressure in the gap and enable the shaft to be clearly viewed. Weather protection may be necessary in outdoor installations. No restriction or pipe shall be fitted to this opening. A continuously falling drain should be led from the bottom of the chamber in order to remove oil and detect leaks. The size of the drain shall be large enough to avoid the risk of blockage.

#### 4.3.7.5.2 Integrally geared oxygen compressors with an air gap

Some integral gear compressor designs have an air gap open to the atmosphere. If they have an air gap open to the atmosphere, they shall be in accordance with 4.3.7.4.1.

#### 4.3.7.5.3 Integrally geared oxygen compressors without an air gap

If there is no air gap, additional instrumentation shall be installed according to Section 10. The interspace between gas seal and gearbox seal shall be vented and drained through drillings in the gearbox and/or volute. Vent sizing shall limit the velocity to 30 m/sec (100 ft/sec).

### 4.3.8 Bearings and bearing housings

#### 4.3.8.1 Bearing type

Radial and thrust bearings should be of the hydrodynamic type, designed to damp out self-excited or externally excited vibration, and designed to accept backward rotation. Pinion radial bearings for integrally geared compressors shall be of the tilting pad design. Use of any bearings other than the hydrodynamic type shall be agreed between the manufacturer and the user.

#### 4.3.8.2 Thrust bearing size

The thrust bearings shall be sized for continuous operation under the most adverse specified operating conditions. Calculation of the thrust force shall include but not be limited to the following factors:

- Seal minimum design internal clearances and twice the maximum design internal clearances;
- Pressurised rotor diameter step changes;
- Stage maximum differential pressures;
- Specified extreme variations in inlet, interstage, and discharge pressures;
- External thrust forces transmitted through the couplings;
- Maximum thrust force from the sleeve-bearing-type drive motor, if the motor is directly connected;
- Thrust forces for diaphragm-type couplings shall be calculated on the basis of the maximum allowable deflection permitted by the coupling manufacturer; and
- If two or more rotor thrust forces are to be carried by one thrust bearing (such as in a gearbox), the resultant of the forces shall be used, provided the directions of the forces make them numerically additive; otherwise, the largest of the forces shall be used.

#### 4.3.8.3 Provision for vibration probes

Bearing housings shall be designed to incorporate the following vibration measuring instruments:

- two non-contacting shaft vibration probes at right angles to one another on or near each high speed bearing; and
- one keyphaser probe per high speed shaft.

#### 4.3.8.4 Bearing failure—Resultant rubs

During normal operational procedures, an agreed amount of limited contact is permitted in the seal (see 4.3.7). The manufacturer shall carry out an analysis to determine what parts of the compressor will rub in the event of a catastrophic rotor excursion, which can be caused by an axial or radial bearing failure. The manufacturer shall make every effort to ensure that the resulting rubs that occur during the compressor rundown shall meet the following criteria:

- The rubbing components shall be any combination of silver, copper alloy, nickel alloy, high alloy steel, for example, a cast iron to low alloy steel rub is not permitted; and
- At the rub site, there is high heat capacity and good heat transfer.

At the design stage, the manufacturer shall supply a table of clearances and materials that demonstrate that these previous requirements have been complied with.

## 4.4 Rotor dynamic analysis, verification tests, and data to be provided

### 4.4.1 Summary

An important contributor to the safe compression of oxygen is a well-designed compressor and an important aspect of the compressor design is a stable and well damped rotor system. An unstable rotor results in high vibrations and large rotor deflections, which in turn cause high speed rubs that are a primary cause of oxygen fires. It is for this reason that this publication emphasises the need for detailed modelling of the rotor system over the whole range of expected operating parameters followed by tests in the workshop or field to verify that the rotor system is satisfactory.

### 4.4.2 References

This publication basically follows internationally recognised standards and practices. API Standard 617 shall be used as the basis including testing and acceptance criteria, with the exceptions and clarifications given as follows [3].

- For compressors with rigid coupling, train analysis shall always be performed [3];
- An internal rub on an oxygen compressor is of much greater importance than on, for example, an air compressor since it represents a possible source of ignition. For this reason, the maximum amplitude of any component within the oxygen envelope shall not exceed 75% of the internal clearance when the displacement at the probe location is at the trip level according to 4.5.2 [3];
- Since stable rotor dynamics are essential for an oxygen compressor, any failure to meet the design requirements shall be rectified to meet the requirements of 4.4. Retesting after modification should be conducted; and
- Verification tests shall be performed using dry, oil-free, air or nitrogen. Blended dry, oil-free gases may be used to reach the correct molecular weight (for example, mixture of carbon dioxide and nitrogen). Oxygen shall not be used for verification tests.

Due to their physical nature, any responding shaft vibrations that occur can always be related to forced, to self-excited, or to parameter-excited vibrations. The sources of these vibrations and their effects on the rotor system shall be analysed by calculations if they are expected to occur in the actual design.

## 4.5 Balancing and vibration

### 4.5.1 Balancing

High speed balancing shall be considered on all rotors running greater than their first bending critical speed. The first bending critical is the mode in the real rotor system corresponding to the first critical of the same rotor in rigid bearings. When performed, the assembled rotors shall be balanced at their maximum operating speed. Balance corrections shall be done according to the mode shapes without any unallowable influence of the low speed balanced quality according to ISO 1940-1, *Mechanical Vibration — Balance quality requirements for rotors in a constant (rigid) state — Part 1: Specification and verification of balance tolerances* [7].

The acceptance criteria to be met for the high speed balancing shall be as follows.

The bearing pedestal vibrations shall be in accordance with ISO 10816, *Mechanical vibration — Evaluation of machine vibration by measurements on non-rotating parts — Part 1: General guidelines* and shall not exceed the following limits [8]:

- At critical speeds = 4.5 mm/s (root mean square [RMS]);
- Within the operating speed range (from minimum operating speed to maximum continuous speed) = 1.8 mm/s (RMS);
- Up to and including trip speed = 4.5 mm/s (RMS); and
- The relative shaft vibrations in normal operating conditions shall be in accordance with API Standard 617 [3].

#### 4.5.2 Vibration alarms and trips

There is no recognised rule for setting alarm and trip levels. Many operators base the setting upon the actual running levels achieved in operation. Unless otherwise specified by the manufacturer of the compressor, the following values set out are based on API Standard 617 and should be regarded as maximum levels provided that these levels are less than 75% of the nominal clearance [3].

- Maximum permissible alarm setting:

$$A = 2.0 \times (25.4 \times (12{,}000/N_{max})^{½})$$

- Maximum permissible trip setting:

$$A = 3.0 \times (25.4 \times (12{,}000/N_{max})^{½})$$

Where:

$N_{max}$ = max continuous speed (rpm)

A = Amplitude of unfiltered vibration in micron peak to peak

### 4.6 Insulation and grounding

Care shall be taken to insulate and ground the electric drive motor correctly to prevent currents circulating through the compressor that, experience has shown, can damage the bearings, couplings, and gear teeth. This phenomenon can occur in all types of compressor but additional care is required in the case of oxygen compressors because the consequence of bearing damage could be a fire. Compressor shafts may be grounded. See Figure 1.

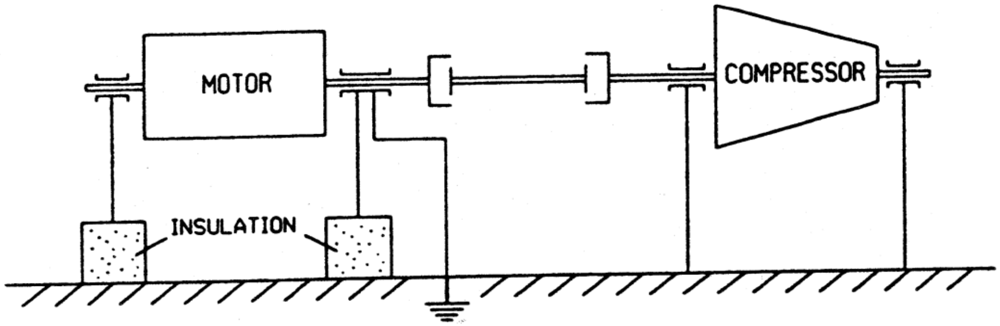



**Figure 1—Grounding of compressor shafts**

## 5 Process pipework

Compressor piping specifications, fabrication, cleaning and inspection shall follow the criteria shown in Section 5, 6, and 7 of EIGA Doc 13, *Oxygen Pipeline and Piping Systems* [9].

### 5.1 Extent

The recommendations and requirements contained in this section shall be limited to the piping directly associated with the oxygen compressor and included within the oxygen compressor unit. In general terms this is the oxygen compressor envelope, which is limited to the piping downstream of the suction isolating valve and will include the inlet filter system, all piping between the compressor and non-integral coolers, bypass valves, and associated piping and discharge piping from the compressor through to the outlet shutoff valve.

### 5.2 Connections

All connections 40 mm (1.5 in) nominal bore or larger shall be flanged or welded.

### 5.3 Welding

The use of backing rings is forbidden. The root runs of all butt welds shall be made by a method that will minimise slag formation, a suitable method would be gas shielded arc welding. The welds shall be smooth and of regular form. Any slag or weld droplets shall be removed.

Welding checks shall be carried out. The methods and extent shall be agreed between the manufacturer and the user.

### 5.4 Prefabrication

To reduce the possibility of contamination on site due to ingress of moisture and dirt, oxygen piping should be prefabricated except for the closing ends. All ends shall be suitably capped prior to dispatch to site.

### 5.5 Vents to atmosphere

Vent outlets shall be directed away from personnel and shall be located so that a concentration of oxygen is avoided. In the case of continuous vents, it is recommended that a dispersion calculation is carried out. The vent line is continuously exposed to the atmosphere and shall therefore be constructed of corrosion resistant material. The design of the pipework shall preclude the accumulation of water [10].

### 5.6 Special piping

Piping downstream of a recycle or dump valve shall be considered as a pressure letdown station and shall meet the requirement according to EIGA Doc 13 . The material selection for the recycle valve and the dump valve as well as the downstream piping shall be agreed between the manufacturer and the user.

A type of pressure reducing system that has proved satisfactory is the use of a matched combination of a valve plus a static pressure reducing device. This is typically either a multi-hole radial diffuser or a multi-plate axial diffuser. In this system the pressure let down is shared between the valve and device and it is normally designed so the velocity in the pipework downstream of the device is sufficiently low to permit the pipework to be made of carbon steel.

The velocity in the individual diffuser holes can be sonic and the materials used shall take this into account. The valve and pressure reducing device should be purchased as a matched pair from the same supplier.

Whatever solution is chosen shall result in acceptable noise and vibration in the pressure reducing system over the complete operating range of the system. The noise level and vibration shall be agreed between the user and valve manufacturer to ensure the integrity of the valve.

The recycle system shall be designed to pass a minimum of 100% of the rated flow at all operating conditions up to the maximum continuous speed. The recycle system, except for the special pressure reducing section described previously, may be made of carbon steel provided that the velocities comply with the limits specified in EIGA Doc 13 [9]. This includes the point of entry to the main suction line and the main suction line itself.

The entry of the recycle stream into the suction line shall be upstream of the suction filter. In order to prevent damage to the suction filter the distance between the entry point and the suction filter shall be not less than twice the diameter of the suction piping.

### 5.7 Bellows

Bellows should be avoided because they can trap dirt and debris and can be difficult to clean. If required, bellows shall be entirely of metallic construction and made from corrosion-resistant materials. They shall have a smooth inner sleeve to reduce turbulence and dust accumulation. Before assembly of the sleeve, the inside of the corrugations shall be inspected for cleanliness.

### 5.8 Gaskets

Refer to 4.2.3.

### 5.9 Acoustic and thermal insulation

Pipe external acoustic and thermal insulation material shall be compatible with oxygen at atmospheric pressure. Care shall be taken to ensure that the pipe insulation is sealed against the ingress of oil vapour. Pipe internal insulation is not permitted.

### 5.10 Silencers

Silencers are forbidden in the recycle or interstage pipework. It is preferred that silencing of the suction is achieved by insulating the suction pipe but if this is not practical the use of suction silencers is permitted. Suction silencers, if fitted, shall be located upstream of the suction filter. The silencer shall be manufactured using oxygen-compatible materials and the design shall be so the possibility of the internals breaking up is prevented.

### 5.11 Vaned elbows

Vaned elbows are permitted. They shall be treated as impingement sites and shall comply with the impingement site velocity criteria according to EIGA Doc 13. The formation of internal slag shall be precluded by the use of a welding procedure that uses inert gas shielding. The design of the vaned section shall facilitate post fabrication oxygen cleaning and inspection.

### 5.12 Main suction filter

A filter shall be provided in the main suction line as close as practicable to the machine inlet flange as agreed to with the compressor supplier. It shall be installed before startup and remain throughout the lifetime of the machine.

#### 5.12.1 Rating

The filter rating shall be capable of capturing all particle sizes larger than 150 micron maximum.

#### 5.12.2 Materials and design strength

Refer to Section 5.

#### 5.12.3 Flow direction

The filter unit shall be designed so all attachments (for example, fasteners) are upstream of the filter elements to be contained within the filter elements if the attachments fail.

#### 5.12.4 Free area

The filter element shall provide an effective open area of at least the area of the main suction pipe.

#### 5.12.5 Precaution against installation errors

The filter unit shall be designed to prevent incorrect installation. An external indicator such as an arrow shall be provided to indicate the direction of flow.

#### 5.12.6 Inspection

The filter element shall be easy to remove for inspection and cleaning. The design of the filter systems be such that during removal, all foreign particles are prevented from going downstream.

## 6 Manual valves

### 6.1 Manually operated main isolation valves

The manually operated main isolation valves are not covered by this publication. Refer to Section 5.

### 6.2 Manual valves that form part of the oxygen compressor envelope

Manual valves that form part of the oxygen compressor envelope, but which cannot be operated while on oxygen and not in oxygen flow path and therefore will not experience high velocity oxygen, may be made of carbon or low alloy steel. Valves that can be operated on oxygen shall be made of copper alloy, nickel alloy, or stainless steel, for example, low point drains and instrument root valves.

# 7 Intercoolers and aftercoolers

## 7.1 Scope of supply

Coolers should be supplied by the compressor manufacturer as it is their ultimate responsibility to ensure that the complete machine is constructed under clean conditions. The user is responsible for ensuring that the manufacturer has been given sufficient information about the water quality to enable the correct materials to be selected.

## 7.2 Types of cooler

Any type of cooler can be accepted, provided that materials are oxygen compatible and that adequate cleaning can be achieved (see also 11.3).

### 7.2.1 Design features—Specific to coolers with gas in the shell

This type of cooler has cooler heads containing the water channels to tube bundle. To ensure a positive inspection for oxygen cleanliness, they should have removable tube bundles.

### 7.2.2 Design features—Specific to coolers with gas in the tubes

This type of cooler should have a single gas pass.

### 7.2.3 Design features common to both types of cooler

Components, for example, bolts, shall be positively secured to avoid the danger of them coming loose and being carried into the oxygen stream.

The design shall minimise the risk of leaks between the oxygen and the water sides.

Cooler tubes shall be properly supported and shall be designed to not be susceptible to machine or fluid induced vibration. The tube supports and baffles shall be of a suitable design and materials to ensure that they do not damage to the tubes. Experience has shown that to achieve this it is recommended that the support material that is in contact with the tube be softer than the tube material.

When the tubes are expanded into the tubesheets, the lubricant used shall be oxygen compatible.

### 7.2.4 Material selections that are common to both types of cooler—Oxygen side only

The materials of the tubes and fins (if any) in contact with the oxygen shall be copper or copper alloy.

If the cooling water quality necessitates that different materials are used, those materials shall be selected and validated through a specific design review and agreed to between the manufacturer and the user.

Commonly used materials are Muntz metal or naval brass for the tubesheets and admiralty brass or 90/10 copper/nickel for the tubes. The fins are normally made of copper.

Tubesheets made from carbon steel can also be used provided that cooling water quality avoids corrosion problems (for example, with closed circuits or appropriate water treatment).

Gasket material in contact with the oxygen stream shall be compatible with oxygen and agreed between the supplier and the user. Gaskets shall not protrude into the gas stream.

### 7.2.5 Establishment and maintenance of oxygen cleanliness—Gas in shell type

One of the concerns with this type of cooler is the oxygen cleanliness of the cooler bundle because:

- it requires specific equipment to clean it after assembly or reclean it if it becomes contaminated; and
- there is no simple way of checking its cleanliness in the field.

The following procedure has been found to work well and is recommended:

- clean for oxygen service, assemble the cooler completely, and seal all openings with heavy blanks in dedicated workshop; and
- ensure that the blanks are only removed under the supervision of the designated person (see 13.1).

If the cooler shell is made of carbon steel or cast iron, the parts that are in contact with oxygen shall be protected against corrosion. Furthermore:

- purging with nitrogen is permitted;
- paint is not permitted;
- zinc coating, in this application, is permitted by this publication with the provision that good adherence is ensured by compliance with the following conditions:
  - hot dipping is the only acceptable process
  - cooler design shall be suitable for hot dipping
  - if zinc coating is used, the preferred thickness of the zinc is between 200 microns to 600 microns but a greater thickness is acceptable if good adherence has been verified; and
- surface passivation as described in EIGA Doc 33, *Cleaning of Equipment for Oxygen Service* is permitted [11].

### 7.2.6 Establishment and maintenance of oxygen cleanliness—Gas in tube type

It is possible to establish oxygen cleanliness in this type of cooler because the gas header can be detached for cleaning and inspection.

Appropriate cleaning equipment shall be used for this type of cooler in the field.

In order to ensure that the cooler remains oxygen clean during shipping and erection, the unit should be sealed with heavy blanks that are only removed under the supervision of a designated person (see 13.1).

Precautions shall be taken for cleanliness preservation and recleaning shall be done when necessary.

## 7.3 Vents and drains

Suitable means shall be provided to vent all high points and to drain all low points on the water side. It shall be possible to check for cooling water leaks to the process side with water circulating prior to starting the compressor.

The oxygen side drains shall be directed to a ventilated area. The minimum pipe diameter of the vent and drain connections should be 20 mm (0.75 in) and equipped with a full bore valve. Vent and drain connection can run in critical flow conditions; therefore, care shall be taken of high velocities and associated risks and appropriate exemption materials selected according to EIGA Doc 13 for personnel protection where necessary [9].

# 8 Lubricating oil system

## 8.1 General

Parts, components, or systems requiring operator access while on oxygen shall be outside the hazard area. Lubricating oil pipes within the hazard area shall be kept as short as possible and be routed clear of oxygen pipework where possible. The number of mechanical joints shall be kept to a minimum and, where their use is unavoidable, they shall be easily accessible and located to avoid the possibility of lubricating oil dripping onto pipework or other equipment.

## 8.2 Oil pumps

A mechanically shaft-driven main oil pump is the preferred method for motor drive compressors in order to provide adequate lubrication during rundown, caused by total loss of power. A shaft-driven oil pump is a pump driven by the shaft of one of the main machines served by the system [12]. All other methods are more complex and require careful consideration. However, if in a particular design the shaft-driven oil pump is not able to provide sufficient lubrication during the rundown period, accumulators or an emergency oil pump should be provided to supply the required oil. Care shall be taken to keep the amount of stored oil in the accumulator to the minimum required so that, in the event of a seal gas failure, the likelihood of oil contamination is still negligible. Severe damage, which can result in a fire, will be caused if a compressor runs down without lube oil. A risk assessment is required to continue to run the compressor on the auxiliary lube oil pump if the main shaft-driven pump has failed.

### 8.2.1 Steam turbine driven units

Experience with steam turbine driven oxygen compressors is limited and the solution is more complex due to the requirement of the turbine bearings to be fed with oil during the cooldown period. In the case where the compressor is shut down and the seal supply has failed a method of automatically isolating the compressor from the lube system shall be provided (see Section 10). In addition, shutting down the rotor turning gear should be considered.

## 8.3 Filter

As a minimum, a single oil filter is required. However, dual oil filters are preferred as they allow for switchover during normal operation of the compressor without interrupting the oil flow to the bearings. The filters should have a 10 micron rating and shall be installed downstream of the cooler. All the lube oil supply pipework downstream of the filter should be stainless steel.

## 8.4 Oil heater

If provided, the surface area of the oil heater shall be so no local overheating or cracking of the oil can occur.

## 8.5 Oil vapour extractor system

The lube oil tank shall be fitted with an oil vapour extractor complete with oil demister system. The design shall be so it shall not be possible to exceed a predetermined negative pressure in the lube oil tank. If the oil reservoir is located within the compressor’s safety barrier, a gas eductor/ejector system is preferred. Alternatively, precautions shall be taken if electrical equipment is used with regards to risk of ignition of oil vapour in an oxygen-enriched atmosphere. Electrical grounding of the system shall be ensured to avoid accumulation of electrical discharge or static electricity. The exhaust piping exiting the oil vapour extractor shall be directed to safe location outside the safety barrier. Non-metallic material shall not be used for the piping of this system. An electrostatic filter shall not be used.

The compressor startup should be interlocked in case the oil vapour extractor system is not working. An alarm shall be provided in the control system, if the oil vapour extractor fails during operation. This can be accomplished by measuring the vacuum in the oil tank or by other means such as operation of the extractor or by the loss of instrumentation air to the ejector.

### 8.6 Oil tank

The lube oil tank shall be installed so that oil spillages during filling are limited to a specific area from which the oil can easily be removed.

In order to protect the oil tank from overpressure, resulting from hot gases generated by a compressor fire, an overpressure protective device vented away from personnel areas should be fitted in the top of the lube oil tank. It should be the same size as the lube oil return line and should have a relief pressure commensurate with the allowable pressure in the lube oil tank.

### 8.7 Control

The temperature and pressure of the oil supply shall be controlled automatically.

## 9 Controls and instrumentation

### 9.1 General

Protective controls and instrumentation shall be provided for every oxygen compressor in accordance with but not limited to those described in the following paragraphs. The minimum alarm and trip requirements are shown in Table 1. All measurements taken inside the hazard areas while the machine is on oxygen service shall be remotely read in a safe environment.

The trip system may be executed by computer software provided that the reliability, integrity, and security are not less than the equivalent hardwired system.

The speed of the tripping system should be as fast as possible; therefore, the slowing down of the system to avoid trips due to transient voltage dips, etc. should be kept to an absolute minimum commensurate with the engineering of a reliable system.

To avoid surge, the compressor should be unloaded or shut down before closing the automatic discharge isolation valve. Unloading should be accomplished by opening the final dump vent valve and recycle valve without delay. The recycle valve shall close slowly (typically 3% to 5% per second).

If a fluid is used in a pressure transducer, it shall be oxygen compatible.

A “first up” or “first out” alarm system is recommended.

The alarm and trip set points shall be agreed between the manufacturer and the user. Alternate setpoints by the user can be applied after a risk assessment is completed, which includes operating history to determine alternate alarm and trip set points that are acceptable.

### 9.2 Control system

The control may be pneumatic, electrical, or hybrid.

**Table 1—Minimum instrumentation of oxygen compressors**

| Function | | Indicator | Alarm | Trip | Interlock |
|---|---|---|---|---|---|
| **1.0** | **Oxygen** | | | | |
| 1.1 | Compressor suction pressure (after filter) | Σ | Lo | (Lo) | |
| 1.2 | Compressor final discharge pressure | Σ | (Hi) (Lo) | (Lo) | |
| 1.3 | Suction filter differential pressure | Σ | (Hi) | - | |
| 1.4 | Compressor suction temperature | Σ | (Lo) | - | |
| 1.5 | Temperature of main gas stream at each process stage outlet (see 9.4). | Σ | Hi | Hi | |
| 1.6 | Temperature after each cooler | Σ | - | - | |
| 1.7 | Compressor flow (see 9.3) | Σ | - | - | |
| **2.0** | **Seal gas system** | | | | |
| 2.1 | Compressor seal gas supply pressure | Σ | Lo | | |
| 2.2 | Differential pressure between seal chambers (refer to Figures 3 and 4 and Section 10) | Σ | Lo | Lo 1) | |
| 2.3 | Bearing seal gas supply pressure | Σ | (Lo) | - | |
| **3.0** | **Cooling water system** | | | | |
| 3.1 | Main supply flow | (Σ) | (Lo) | - | (Lo) 2) |
| **4.0** | **Bearings and lube oil system** | | | | |
| 4.1 | Oil filter differential pressure | Σ | (Hi) | - | |
| 4.2 | Oil supply pressure after filter and cooler | Σ | Lo | Lo 3) | |
| 4.3 | Temperature in oil supply manifold to the compressor | Σ | Lo | - | Lo 2) |
| 4.4 | Temperature of each journal bearing | Σ | Hi | (Hi) 4) | |
| 4.5 | Temperature of each thrust bearing | Σ | Hi | (Hi) | |
| 4.6 | Main tank level | Σ | Lo | (Lo) | (Lo) |
| 4.7 | Main tank loss of vacuum | Σ | Hi 5) | | |
| **5.0** | **Shaft position and vibration** | | | | |
| 5.1 | Axial position (see 9.7.1 2) | Σ | Hi | Hi | |
| 5.2 | Radial vibration of high speed shaft at each bearing location (see 9.7.7.1) | Σ | Hi | Hi | |
| **6.0** | **Miscellaneous** | | | | |
| 6.1 | Speed (in case of variable speed drive) | Σ | - | Hi | |
| 6.2 | Surge detection (9.3.3) | - | - | Σ | |

NOTES

- = not required
Σ Hi, Lo = mandatory
(Σ), (Hi), (Lo) = recommended

1) Interlock with auxiliary oil pump (see Section 10).
2) Interlock to prevent startup.
3) Starts auxiliary pump (see Section 8).
4) Trip on bearing temperature is mandatory for geared compressor.
5) Loss of vacuum/high pressure.

## 9.3 Anti-surge system

#### 9.3.1 Introduction

A compressor in surge is subject to flow reversal, thrust reversal, rotor vibration, and heating. Compressors are built to withstand a certain amount of surging without damage; however, if the compressor is allowed to surge continuously, severe damage can result. The consequences of an internal rub can be much more severe in oxygen service than other gases, therefore, specific considerations shall be taken in the design of the anti-surge system.

Protection against damage due to surge takes two forms:

- modulating the anti-surge system to keep the compressor out of surge; and
- surge detector to shut down the compressor in the event of surge.

#### 9.3.2 Modulating anti-surge control

The compressor is prevented from going into surge by the action of an automatically controlled recycle valve that allows gas to flow from the discharge (via a cooler) to the suction.

The system shall be designed to prevent the operator from overriding the automatic anti-surge controller.

The anti-surge control shall be designed to prevent the compressor from going into surge under all foreseen operating conditions and upset conditions. It is recognised that if there is a sudden failure in the system, the compressor can surge and be shut down by the surge detector system (see 9.3.3).

When the compressor anti-surge system is being designed, the following points shall be considered:

- Operation of quick acting valves downstream of the compressor can be a potential cause of surge and for this reason the entire anti-surge control system shall have a fast response time;
- The recycle valve and its associated downstream pipework shall be designed for continuous operation;
- If operation close to surge is required, the effects of changes of pressure and temperature (gas and cooling water) on the surge characteristic should be considered;
- The position of the suction throttling device relative to the recycle line (see Figure 2). If the device is positioned downstream of the recycle line, it shall be equipped with a mechanical minimum opening stop so that there is still sufficient flow area to allow the anti-surge system to be effective;
- There is no simple algorithm that describes the position of the surge line of a multi-stage, intercooled centrifugal compressor under varying conditions of capacity control, suction, and cooling water temperature. The complexity of the modulating anti-surge system depends upon how close to surge it is intended to operate, variation in operating conditions, and severity of the potential system upsets;
- The anti-surge control line shall be set at least 8% by flow (at the operating pressure) from the surge line unless a risk assessment of the surge control system allows for a lower margin. The following verifications shall be done:
    - The manufacturer shall calculate the surge points depending on-site conditions (i.e., varying inlet and cooling water temperatures). These predicted surge points shall be checked on site over as wide a range as possible
    - When the surge map has been produced, an anti-surge controller shall be designed to fit the surge map

    - Consideration should be given to fitting a device that senses the rate at which the compressor is approaching surge and, if this is greater than a predetermined value, the recycle valve is opened a preset amount. The subsequent action depends upon the design of the system; and

- The anti-surge control system shall meet the following requirement:

    - The anti-surge controller can be either analogue or digital. If digital, the calculation shall be made a maximum of every 100 milliseconds. The shorter the calculation interval the quicker the possible system speed of response.

It is considered acceptable to use the main plant control computer to carry out the anti-surge control functions provided that it can meet the previous speed requirements and that it is as secure as a separate standalone controller. No delays, other than those required to combat transient electrical disturbances, shall be permitted.

#### 9.3.3 Surge detection shutdown device

A surge detection and shutdown device shall be fitted. This shall trip the compressor after a maximum of 4 surges within a period of time as determined by the user, thus safeguarding it from damage in the event of failure of the anti-surge control.

This device and the modulating anti-surge control system shall be designed so that the risk of common mode failure is minimised.

Axial vibration, reverse flow detection, differential pressure (dP), or discharge pressure fluctuation shall be used for surge detection.

### 9.4 High oxygen temperature protection

Temperature sensors shall be installed in the oxygen path at each process stage outlet. They shall be positioned as close as practicable to the discharge nozzle and they shall be located before the first elbow. The temperature sensors can also detect a fire to initiate a trip and isolate the compressor.

The alarm and trip set points shall be agreed between the manufacturer and the user, unless a risk assessment determines that alternate alarm and trip set points selected by the user can be used.

If production reliability is a concern, 2 out of 3 voting should be utilised.

Most experience exists for an operating temperature less than 200 °C (392 °F), which shall be considered as a maximum operating temperature.

NOTE—Temperatures greater than the maximum main gas stream temperature can be found in certain parts of the compressor. These are normally areas where low gas velocities and high rotational speeds are found (for example, behind the impellers). However, since it is not practicable to measure these temperatures in production machines, they are not used as limiting parameters.

### 9.5 High bearing temperature protection

The temperature of all high speed bearings shall be monitored with embedded temperature sensors. The measurement of the oil temperature leaving the bearing is not acceptable.

NOTE—In the case of tilting pad bearings, it is important to measure the temperature of the loaded pad(s) and ensure that the sensing device does not restrict the movement of the pad(s).

### 9.6 Overspeed protection

For variable speed drives, an overspeed protection system shall be installed.

## 9.7 Vibration and shaft position

### 9.7.1 Compressor

#### 9.7.1.1 Radial vibration

Two vibration probes shall be fitted at 90 degrees from each other at each high speed bearing location.

#### 9.7.1.2 Axial position

Non-contacting probes to monitor the axial position of high speed shafts shall be used for shafts with high speed thrust bearings and should be used for shafts with thrust collars. If axial probes are not fitted to high speed shafts with thrust collars, the axial position of the relevant slow speed shaft shall be monitored with a non-contacting probe.

The measurement point should form an integral part of the shaft.

#### 9.7.1.3 Keyphaser

Provision shall be made to fit a keyphaser probe on each high speed shaft.

### 9.7.2 Gearbox

High speed parallel shaft of separate gearboxes shall have probes that meet the same requirements as the compressor (see 9.7.1.1).

Epicyclic gearboxes shall be fitted with an accelerometer-based alarm and trip system.

### 9.7.3 Vibration probe monitoring system

The unfiltered output of at least one radial probe per location and the output of all axial probes shall be monitored continuously.

The time delays built into the alarm and trip system shall be reduced to a minimum. For more information, see API Standard 670, *Machinery Protection Systems* [13].

Failure of the system shall give an alarm and should initiate a trip.

Provision shall be made to enable connection of analysers for vibration frequency and phase analysis.

If starting on inert gas, a manual or time delay startup override is acceptable. If starting on oxygen, the trip system shall remain live and starting can be achieved using a “trip multiplier” during the run up period.

## 9.8 Safety shutdown system valves

### 9.8.1 Purpose

The purpose of the safety shutdown system is to isolate the oxygen compressor and dump the oxygen inventory and minimise the consequences of a possible fire.

The system shall consist of the following valves:

- automatic suction isolation valve;
- discharge non-return valve;
- automatic discharge isolation valve;

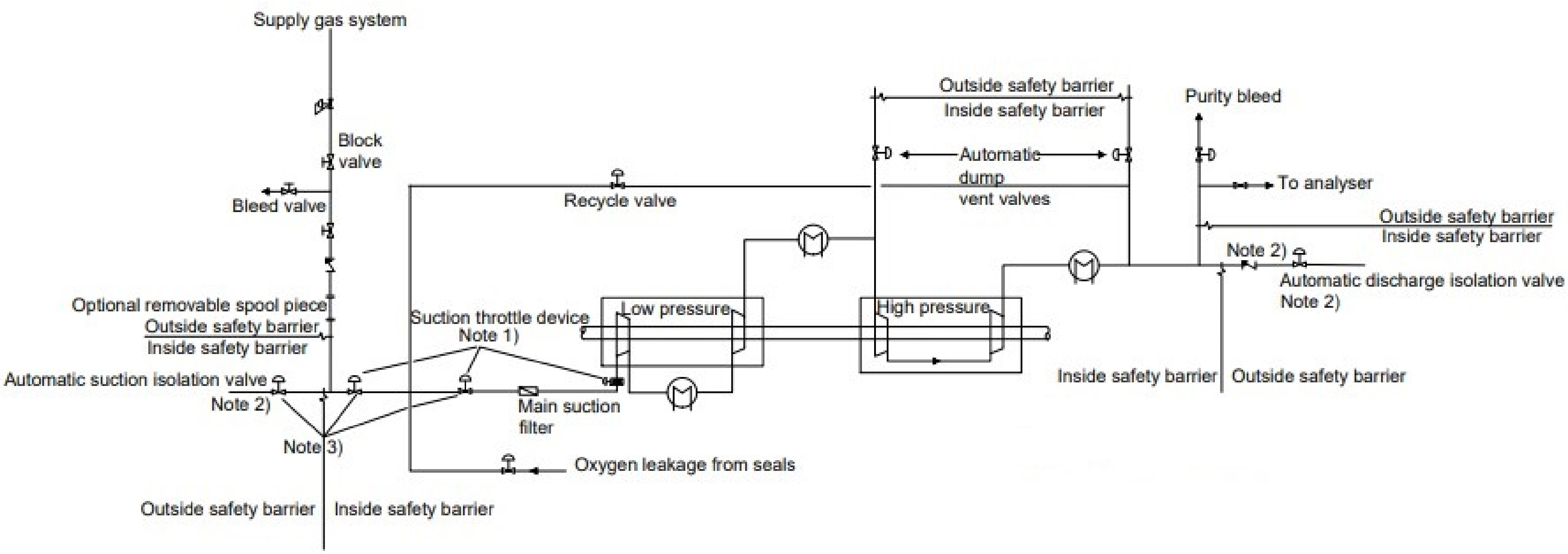
- high pressure and low pressure (if required) dump vent; and
- recycle valve.

The failure modes and operating speeds should be as shown in Table 2 and their position in the system according to the Figure 2.

If the low pressure coolers are gas in shell, a low pressure dump vent is sometimes required to meet the requirement of reducing the discharge pressure to 0.1 MPa (14.5 psi) in 20 seconds (see 12.8.2).

### 9.9 Oxygen humidity

If a dew point indicator is provided to detect water leaks, it should be able to be installed downstream of individual coolers.




NOTES

1 The purpose of this figure is to show the relative positions of the principle valves and their position with respect to the hazard area.

2 The symbols used denote a function and not a specific type of equipment.

1) The figure shows alternative positions for the suction throttle device. See 9.3.2.

2) The non-return valve and the automatic isolation valves may be placed inside the barrier provided they are adequately shielded. See 12.4.3.

3) A single valve may be used to perform the throttling and isolation function.

**Figure 2—Centrifugal oxygen compressor system flow diagram**

**Table 2—Failure modes and operating speeds of system valves**

| No | Valve action | | | Speed of action |
|---|---|---|---|---|
| | On compressor shutdown | On loss of control signal | On loss of electrical signal or motive power | |
| Automatic suction isolation valve [1] | Shut | Not applicable | Shut | 10 sec [2] |
| Automatic discharge isolation valve | Shut | Not applicable | Shut [3] | 10 sec [2] |
| Final dump vent valve | Open | Open (if fitted with I/P) | Open | 2 sec max [4] |
| Intermediate dump vent valve (if fitted) | Open | Not applicable | Shut | 2 sec max [4] |
| Recycle valve | Open | Open | Open | 2 sec max |

[1] For normal shutdown, the automatic suction valve can remain open if the suction pressure is less than 0.1 Mpa (14.5 psi).

[2] The (maximum) time given for closing the isolation valves shall be adjusted so that the dump vent valves and recycle valve have opened first.

[3] If the valve loses supply, it will fail into the correct position for isolating the compressor and may lead the compressor toward surge. However, the compressor is protected against surge according to 9.3.

[4] Auto reclose after 1 minute or when system is depressurised (see 12.8.2).

## 10 Seal gas system

### 10.1 Compressor seal gas system

The seal gas shall be dry, oil-free, air, argon, or nitrogen. The compressor seal system shall maintain proper pressure differentials between sealing chambers under all possible operating conditions. This ensures proper gas flow direction within the seal. Special attention in this regard shall be paid to the transient pressures during startup and shutdown periods where adverse pressure differentials can occur.

Differential pressure measurement devices shall be installed at each shaft seal location to signal adverse pressure distributions, and to shut down the compressor automatically in case of an unsafe seal chamber pressure distribution. See Figures 3 and 4 and 4.3.7.2.

In order to protect the compressor from the possibility of oil contamination when the seal gas supply has failed the seal gas and lube oil systems shall be suitably interlocked. See 10.3 and 4.3.7.2.

The pipework downstream of the compressor seal gas filter shall be made of non-rusting material, normally copper or stainless steel.

The seal gas filter shall have a rating of 10 micron or less.

### 10.2 Bearing seal gas system

This system has the simple function of preventing atmospheric air that can be enriched with oxygen from getting into the oil system. It is not required to have the same high integrity as the compressor seal gas system, nor is it subject to process variations; therefore, it is a much simpler system.

### 10.3 Schematic diagrams

Figures 3 and 4 and following items show the compressor seal gas systems in detail for both single shaft and integral gear compressors.

- Sources of seal gas —Figures 3 and 4 show both the compressor seals and the bearing seals being fed from the same supply. In order to ensure that there is no possibility of oil vapour back flowing along the bearing seal gas line and being pushed in to the compressor seal gas line, the bearing seal system shall be supplied with a separate non-return valve and pressure regulator. The pipe run from the branch off the compressor seal gas system to the nearest bearing shall be at least 5 m (16.4 ft) to minimise the risk of contamination by migration of oil. The compressor seal gas supply shall also be supplied with a non-return valve and pressure regulator to ensure that there is no possibility of oxygen getting into the seal gas supply header.

  An equally acceptable option is for the bearing seal gas and the compressor seal gas to be supplied from separate sources, for example, nitrogen for the compressor seal gas and instrument air for the bearing seal gas. In this case the bearing seal gas piping and system does not have to be oxygen clean or is a minimum length of line between the supply point and the nearest bearing required;

- Interlock with auxiliary lube oil pump—The interlock shown (low differential pressure between the seal centre chamber and seal outer chamber causes the compressor to trip and prevents the auxiliary lube oil pump from starting) is the best system for motor driven compressors with mechanically driven oil pumps;

- Control of the pressure in the seal inner chambers of the compressor shaft seal system—If the inner chambers of the seal system are connected to the suction pipework up stream of the suction throttle device (if fitted), pressure in them will remain constant.

  If the seal inner chambers are connected downstream of the throttle device, the pressure in them will vary according to the amount of suction throttling. In extreme cases, this could cause the pressure in some of the seal inner chambers to become subatmospheric.

  When starting up on total recycle with the suction and discharge isolation valves shut, the suction pressure will often drop well below atmospheric pressure for a period of several minutes and there is consequently a risk of dirt and damp air being sucked into the compressor via the vent and the seal centre chambers.

  If this ingress of dirt and air is considered to be a hazard or represent a product purity problem, it is recommended that a backpressure valve is fitted in the line between the seal inner chambers and the suction thus ensuring that the seal inner chamber pressures are always kept positive and constant. Experience has shown that a self-acting control valve is not accurate enough for this application.

  If the problem only occurs during startup, a power operated valve that is shut during startup and trip but open during normal operation is an effective solution. This system has the advantage over the backpressure valve in that it maintains the seal inner chambers at the lowest possible pressure and therefore, minimises the leakage of oxygen to atmosphere via the seal centre chambers.

  The mandatory protection of low differential pressure between seal outer chamber and seal centre chamber at each seal location protects against failure of the seal gas supply and dangerous failure of any of the seal components. This has been proven to be effective. However, failure of the inner section of the labyrinth seal will only be detected when it causes the seal centre chamber pressure to rise; by this time there will be a large flow back to suction. It may be of advantage to detect this leakage early. There are two methods:

  - monitor the differential pressure between the seal inner chamber and seal centre chambers; and

  - monitor the flow in the return line to suction;

- Seal pressure sensing points—The actual position at which the seal chamber pressures are sensed is very important and is discussed fully in 4.3.7.2;

- Gears for single shaft compressors—If the gears are situated within the hazard area, the bearing seal gas system shall be connected to the gear case and the gas used shall be nitrogen.

Consideration should also be given to the fitting of a differential pressure indication, alarm and trip between the gear case pressure and the bearing gas supply pressure; and

- Geared compressor seal gas supply schematic diagram—Geared compressor designed with a seal gas system with an open air gap shall have at least a pressure differential measurement between C and D with the associated alarms and trips.

  Otherwise, additional pressure differential measurements between ports D and E shall be used with alarms and trips.

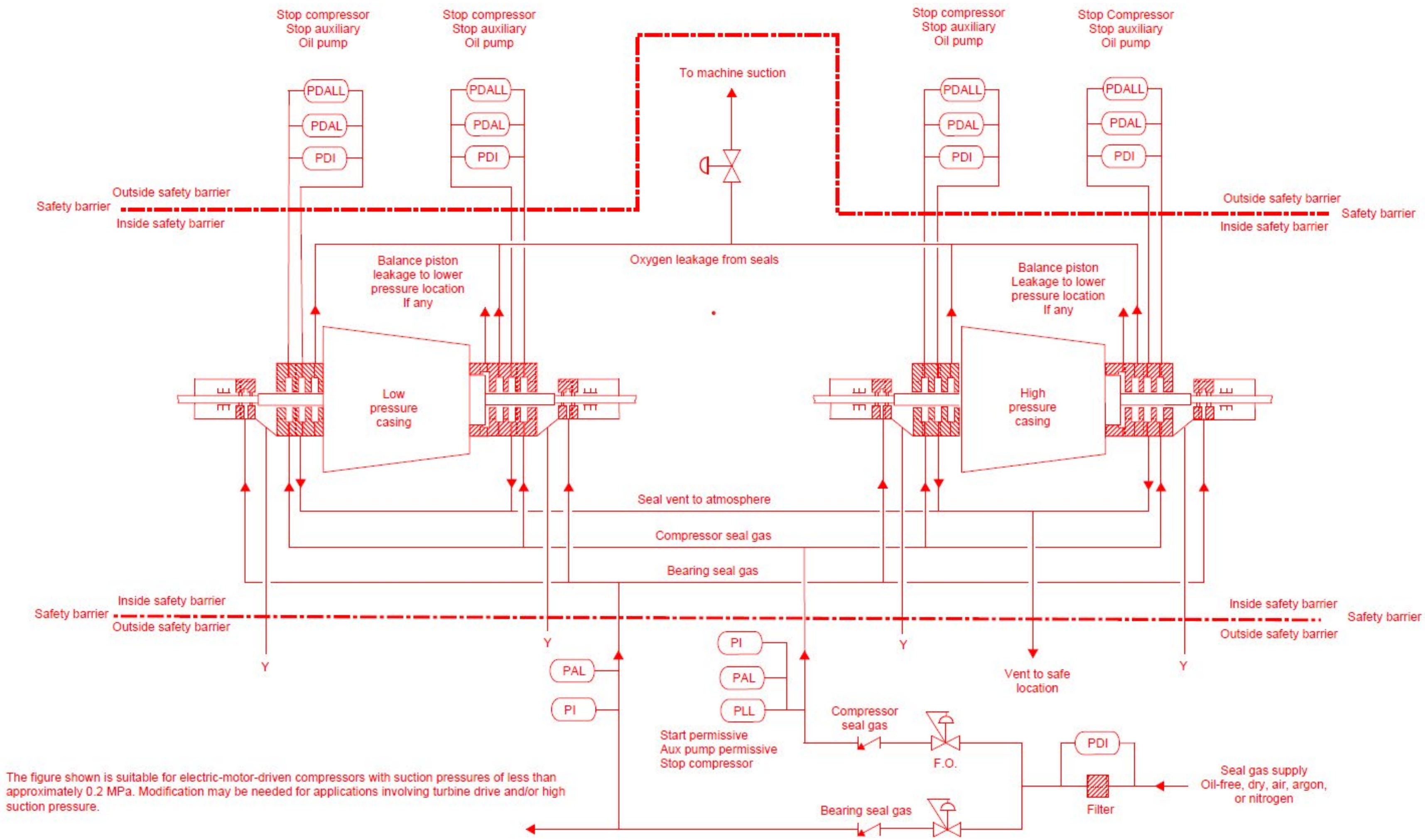



**Figure 3—Example of a single shaft gas supply schematic diagram**

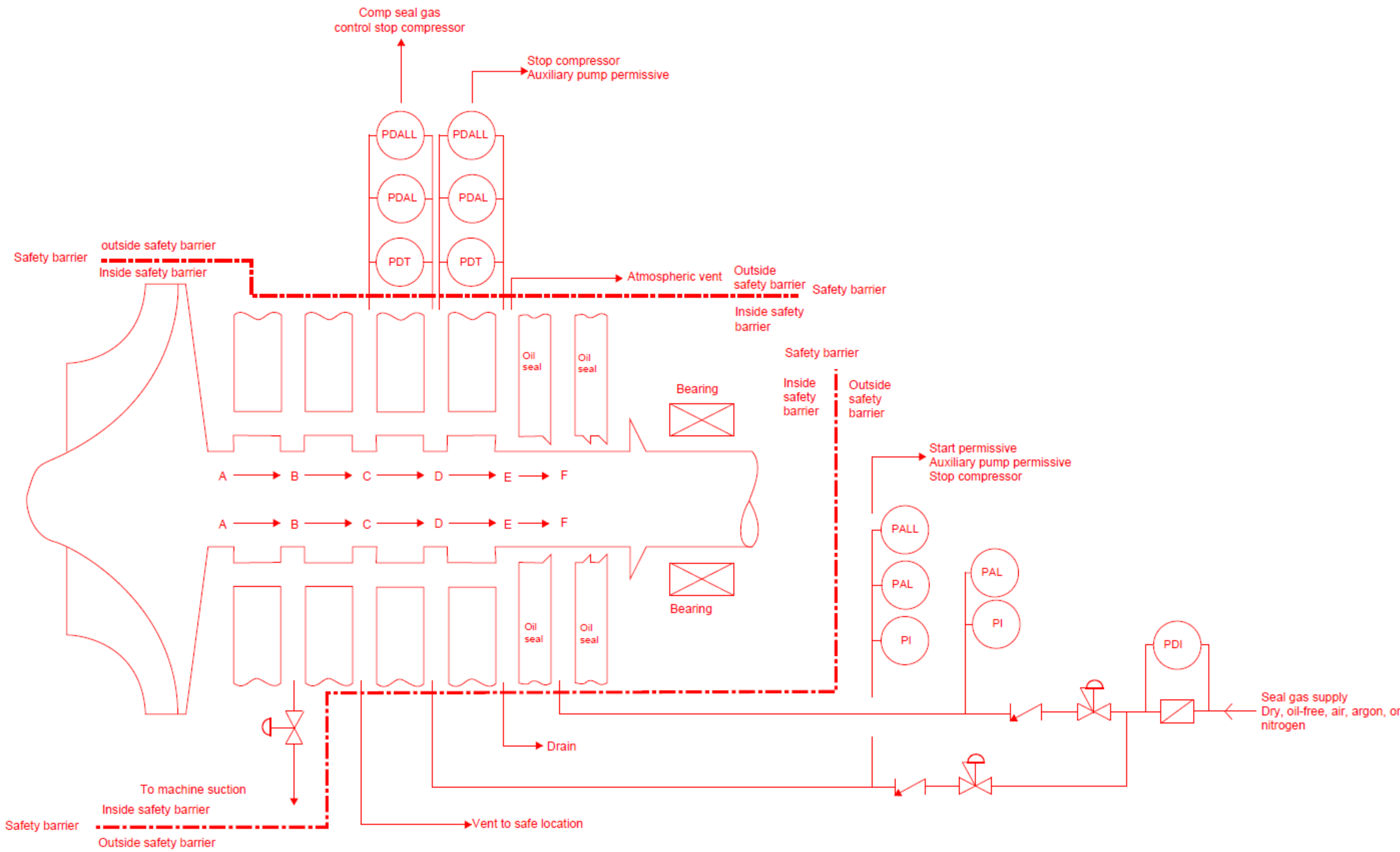



**Figure 4—Example of a geared compressor seal gas supply schematic diagram**

# 11 Inspection and shipping

## 11.1 Introduction

Compressors can be shipped from supplier's works either as fully assembled, tested, oxygen clean units or as separate components to be erected on site. This can include site fabricated piping. Any combination of these two options is also possible.

## 11.2 Responsibility

Whatever the extent of prefabrication, there shall be a designated person responsible for ensuring that the compressor is correctly erected in the field and oxygen cleanliness is maintained. On request, the manufacturer or their representative shall provide from their staff an experienced oxygen compressor erector, who will be in charge of the unit until it is handed over to the user.

## 11.3 Inspection and cleanliness standards

The cleaning methods and acceptance criteria to be followed shall be those shown in EIGA Doc 33 [11].

- The criteria "clean for oxygen service" shall apply to all parts that come in contact with oxygen process gas;
- Related systems that supply gas to the oxygen compressor such as seal gas, purge gas, and startup gas shall be free of particles and hydrocarbons; and
- During the reassembly phase of an oxygen compressor, each part that contacts the oxygen stream or is in contact with ejected seal gas that can have high concentrations of oxygen gas shall be cleaned and inspected in accordance with EIGA Doc 33 before installation is permitted [11].

## 11.4 Preservation of oxygen cleanliness during shipping and storage

### 11.4.1 Equipment

All equipment sent to site "clean for oxygen service" shall be protected against contamination and corrosion. A label or tag stating, "cleaned for oxygen service" shall be visible from outside the package. The size and complexity of the equipment being shipped dictates the appropriate method of preservation.

### 11.4.2 Individual components

Individual items such as valves, regulators, filters etc., that are being shipped separately shall be protected in accordance with EIGA Doc 33 [11].

### 11.4.3 Subassemblies that can be made pressure tight

#### 11.4.3.1 Rust protection not required

Subassemblies that do not require protection against rusting, for example, a gas in shell cooler with a stainless steel shell, shall have their openings sealed with full-face gaskets of oxygen-compatible material and substantial covers of wood or metal. Plastic plugs or gaskets secured with tape are not permitted.

#### 11.4.3.2 Rust protection required

Subassemblies that require protection against rusting shall have their openings sealed with gaskets and metallic covers. Their integrity shall be demonstrated before leaving the suppliers' works by leak checking against a low internal pressure. All spaces shall be blown out with dry, oil-free, air or nitrogen before the subassembly is sealed.

Rust protection can be provided by one of the following means:

- Attaching bags of desiccant that contain colour change additive to detect moisture. These bags shall be attached to the inside of appropriate opening covers and elsewhere within the subassembly as required. The number, position, and reference colour of the desiccant bags shall be painted on the subassembly exterior; or
- Pressurising the subassembly with dry, oil-free nitrogen. The subassembly shall be fitted with a pressure gauge with a plugged or capped recharging valve and have a notice painted on it warning that it is pressurised.

Colour-change-type moisture detectors shall be fixed to the inside of selected opening covers to give confirmation that the preservation measures have been effective, for example, comparing the colour of the desiccant bags to the reference colour.

#### 11.4.4 Arrival on site

When oxygen clean components and subassemblies arrive on site, the preservation arrangements shall only be altered or removed with the approval of the designated person.

If the preservation is found not to be intact and if the moisture detectors (if fitted) have changed colour, the subassembly shall be opened for inspection and recleaned until the designated person is satisfied that the equipment is clean for oxygen service.

## 12 Compressor installation

### 12.1 Hazard area

#### 12.1.1 Considerations/Factors

It is necessary to consider a number of pertinent factors when determining whether or not an area should be classified as a hazard area. These include:

- specific equipment service conditions of pressures, temperatures, gas velocities, purity, contaminants, etc.;
- compressor and other system equipment design factors such as type, size, materials of construction, operating speed, rotor dynamics, internal clearances, type of seal system, etc.;
- history for equipment of similar design and operating conditions;
- extent of safety monitoring and shutdown devices that provide early detection of problems before equipment failure;
- proximity of oxygen equipment to personnel walkways, work areas, and other equipment; and
- plant operators' standards, local government requirements, or other specific requirements.

The hazards that can result from a compressor fire include:

- jets of molten metal;
- projectiles;
- flash;
- blast and overpressure; and
- energy release in the gear case (if situated within the hazard area).

It is the responsibility of the user to specify the extent of the hazard area on a case-by-case basis.

### 12.2 Enclosure of the hazard area by a safety barrier

In most instances, the hazard produced by a centrifugal oxygen compressor is such that the resultant hazard area is so large as to be impracticable unless its extent is reduced by enclosing the compressor within a safety barrier. The extent of the hazard area is specific to the size and pressure of each application.

If the user proposes not to enclose the hazard area within a safety barrier, the user shall analyse the hazard, determine the extent of the hazard area, and demonstrate that the required safety criteria can be met without the use of a barrier.

Barriers shall be installed at greater than 2.0 MPa (290 psi) discharge pressure. However, in current practice, most users have adopted a 0.4 MPa (58 psi) limit. A risk assessment shall be conducted and documented if compressors operating at greater than 0.4 MPa (58 psi) but less than 2.0 MPa (290 psi) are installed without barriers. National regulation may require a safety barrier for less than 0.4 MPa (58 psi).

In case of multiple oxygen compressor systems, barrier walls should be installed between the compressors to separate the individual compressors. Barrier walls should not be used to support utilities, instrumentation, etc., for compressors and equipment other than those contained within the barrier.

## 12.3 Access to the hazard area

When the compressor is operating on oxygen, access to the hazard area shall not be permitted without approved written procedures and shall only be carried out by trained personnel with the appropriate personal protective equipment (PPE). Entry into the barrier shall not be permitted when the compressor is operating with oxygen in a non-steady state. Warning notices to this effect shall be posted. Maintenance access panels shall be closed. Routine visual inspection shall be done remotely through approved safety windows or by using cameras or other devices.

Before entering the hazard area, after the compressor has been shut down or changed over to dry, oil-free, air or nitrogen , the atmosphere within the enclosure shall be analysed to ensure that it is safe to enter. The oxygen concentration shall be between 19.5% and 23.5%. When personnel are within the area, the oxygen concentration shall be continuously monitored.

## 12.4 Equipment location

### 12.4.1 Equipment that shall be inside the hazard area

- compressor casings/volutes;
- intercoolers and aftercoolers and interstage piping;
- suction filter;
- throttling valves and their downstream piping to the first elbow or tee, for example, recycle valve, automatic dump vent valves, suction throttle valve;
- first elbow in each pipe to and from the compressor; and
- piping components subject to sonic velocities or high velocity impingement.

### 12.4.2 Equipment that shall be outside the hazard area

- All instrumentation except primary sensing elements, vibration and position proximitors, and temperature measurement junction boxes; and
- All valves and controls that require manual adjustment while the unit is operating on oxygen service shall be capable of operation from outside the safety barrier.

### 12.4.3 Equipment that may be either inside or outside the hazard area

- Power operated isolation valves and discharge check valve—If located inside the hazard area, these valves shall be protected from the effect of the fire with their own shield;

- Gearbox and lube oil reservoir—The gearbox and lube oil reservoir location is determined by the compressor design and equipment layout;
- Driver—If the drive is not an electric motor, it shall be outside the hazard area. In the case of an electric motor drive, it should be located outside the hazard area;
- If the motor is located inside the hazard area, the safety barrier ventilation should be arranged so that air from outside the enclosure is drawn across the motor to ensure that in the event of an oxygen leak an oxygen concentration build up around the motor is minimised; and
- Lubricating oil system—If located inside the hazard area, the number of connections shall be minimised to prevent oil leaks.

## 12.5 Safety barrier

### 12.5.1 Purpose

The primary purpose of a safety barrier is to prevent injury to personnel. It has a secondary function in that it lessens damage to adjacent equipment. A safety barrier achieves this by preventing flames, jets of molten metal, or projectiles that have caused burn through of any of the oxygen containing equipment within the hazard area from penetrating or collapsing the barrier in the event of an oxygen fire.

### 12.5.2 Responsibilities

It is the responsibility of the user to design and specify the safety barrier. The manufacturer shall supply any necessary information as required.

### 12.5.3 Nature of burn through

#### 12.5.3.1 Likely burn through positions

The majority of fires start in areas of high internal component or gas velocity. Therefore, the areas around the impeller or recycle valve are likely sites. Burn through is most likely to occur at places close to the potential ignition point where the gas pressure and/or velocity are high and the thermal mass is low. Therefore, the primary risk areas are:

- compressor casing;
- compressor shaft seals;
- expansion bellows adjacent to the casing/volute;
- first and second bends in the process pipework immediately upstream and downstream of the compressor flanges;
- recycle valve and its associated outlet pipe and the first downstream bend;
- intercoolers and aftercoolers;
- strainers;
- drain and vent connections; and
- safety valve piping systems.

### 12.5.4 Results of burn through

#### 12.5.4.1 Jet of flame and molten metal

A jet of flame and molten metal can burn through equipment on to which it impacts directly, unless this equipment is of large thermal mass or is protected by a fire-resistant heat shield. The barrier shall also be strong enough to withstand the impact of the jet.

#### 12.5.4.2 Spray of molten metal

Accompanying the jet is a widening spray of molten metal that spatters equipment over a wide area.

### 12.5.5 Blast and overpressure effect

Blast and overpressure effect is caused by the release of high pressure gas and can cause the barrier to collapse unless it has been allowed for in the design. Normally, the barrier is designed to withstand a certain overpressure and a sufficient vent area is provided to ensure that the design overpressure is not exceeded. This is a particularly difficult design problem in the case where the safety barrier is also an acoustic shield.

### 12.5.6 High velocity projectiles

The release of pressure and the rotational energy of the rotor accelerate projectiles that either pass through holes burnt in the casing or rip holes in the casing and go on to hit the safety barrier. The barrier shall be strong enough to withstand the impact.

### 12.5.7 Strength and burn through criteria

The barrier shall withstand the force resulting from the impact of a jet of molten metal issuing from a hole burnt in the compressor or pipework, hitting the safety barrier, plus the overpressure due to the release of the stored inventory of the oxygen. The previous requires calculation on a case-by-case basis because it varies with the size and the discharge pressure of the compressor. The minimum force that the barrier shall be able to sustain is 2 kPa (0.29 psi) projected over the wall area. This value is based on the accumulated industry experience.

The barrier shall be designed to resist the effect of a jet of molten steel for 30 seconds without being breached (see 12.5.5).

Therefore, the design shall consider the following load types:

- sustain temperature of molten metal;
- blast and overpressure; and
- projectile impingement.

### 12.5.8 Materials of construction

Concrete safety barriers are a very effective way of meeting the strength and burn through criteria and have been used successfully (see 12.5.4). Experience has shown that the concrete can be badly damaged but not breached by the direct impact of molten metal and flame.

Steel structures have been used successfully. The detail design shall ensure a structure that has no weak point that can be breached by the overpressure or the impact from jets of molten metal or projectiles. Structural steel members, carbon steel walls, doors, and closure plates that are likely to be exposed to the impact of a jet of molten metal shall be protected by a fire-resistant heat shield.

The fire-resistant heat shield may be a plaster like material that is “trowelled” on or it can be in the form of panels. Calcium silicate or shale board has been found to be effective. Not only shall the material form an effective heat shield but it shall also be mechanically strong enough to resist the scouring effect of the jet of molten steel. It is for this reason that the mineral wool used in acoustic shields is not acceptable as a heat shield in this application. The fire-resistant heat shield shall be supported so that it is prevented from being broken up by the force of the jet. Experience has shown that a layer of heat-resistant material 20 mm (0.75 in) thick can satisfy the required burn through criteria.

If provided, inspection ports shall be covered with reinforced glass or equivalent and shall meet the required strength criteria.

#### 12.5.9 Layout of the safety barrier

The safety barrier shall meet the following criteria:

- Vertical sides shall extend at least 0.6 m (2 ft) and 15 degrees in the vertical elevation view higher than the height of any part of the compressor or piping that contains oxygen and no less than 2.4 m (8 ft) higher than the walking area;
- Safety barrier shall block any line of sight to permanently installed platforms or buildings within 30 m (100 ft) that have normal traffic or occupancy;
- Allowances shall be made for normal maintenance;
- Design of the safety barrier shall be such that, when all the closure plates are in place and the doors are shut and locked or latched, the wall provides a complete unbroken barrier with no weak spots. Consideration shall be made for emergency egress. Labyrinth entrances are also allowed as shown in Figures 5a and 5b;
- If the safety barrier has a roof, ventilation ports shall be located at high levels pointing in a safe direction;
- If the safety barrier is designed with openings for personnel access, it shall have at least two outward opening exit doors or labyrinth entrances at each level and sufficient walkways to allow quick exit; and
- Safety barriers shall be designed to cope with the inventory of high pressure gas that is released when burn through occurs. If the safety barrier has an open top or a partial roof, this does not represent a problem. If the compressor is fully enclosed, normally for acoustic reasons, sufficient open area shall be provided to avoid over pressuring the enclosure. The following ways of achieving the required open area are recommended:
    - Permanently open area with acoustic splitters;
    - Acoustic louvers that are self-opening;
    - Acoustic doors that are self-opening, hinged so as to have a small angular moment of inertia; and
    - Concrete or steel caps that are lifted by the gas pressure, provided that the caps are adequately restrained.

  The open area shall be sited away from the compressor where the hazard is least. The open area shall be sited in a position so that the operation of the doors and the blast of hot gas shall not cause a hazard to personnel.

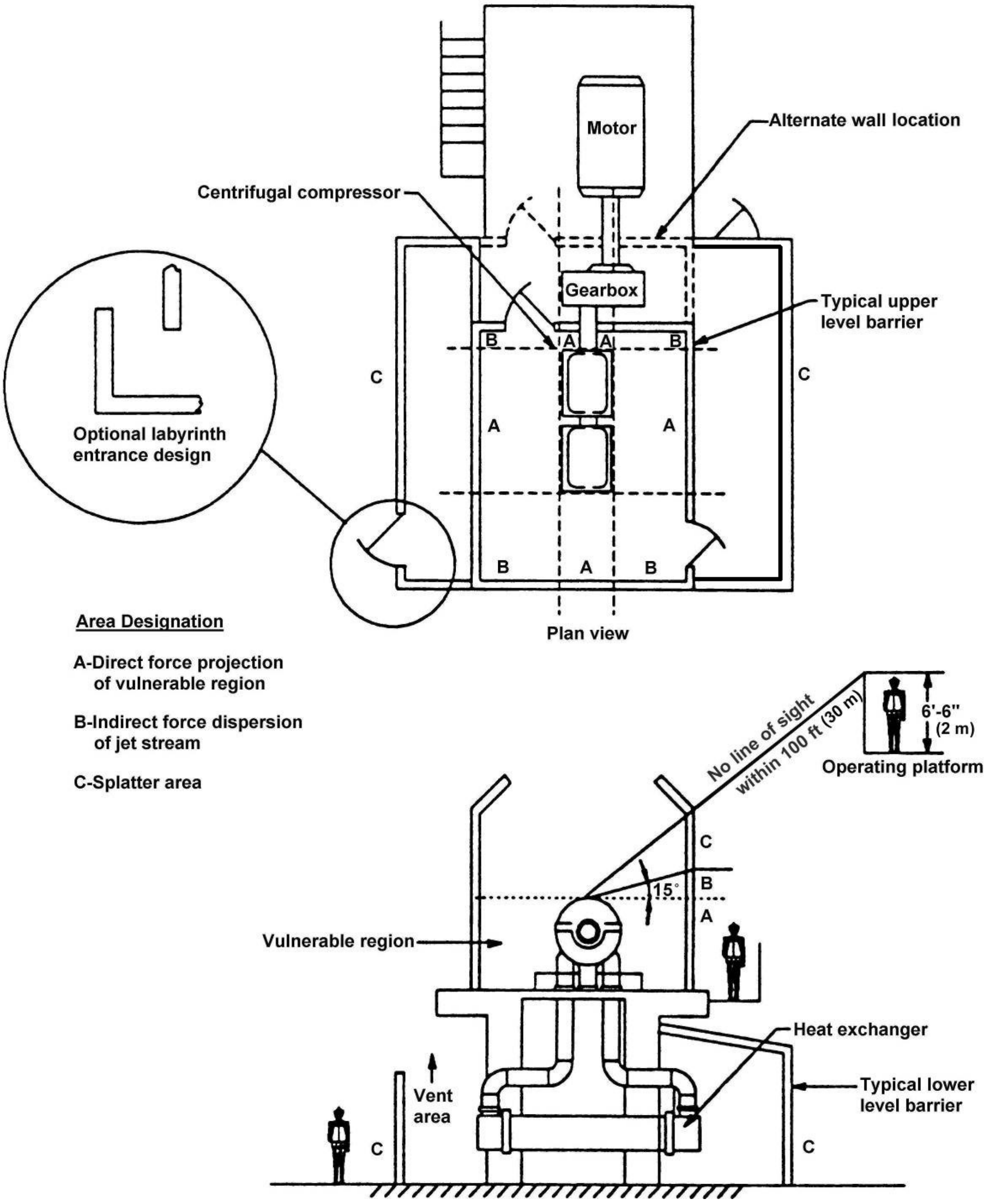



**Figure 5a—Example of a single shaft centrifugal oxygen compressor impact force distribution on barrier (plan and front views)**

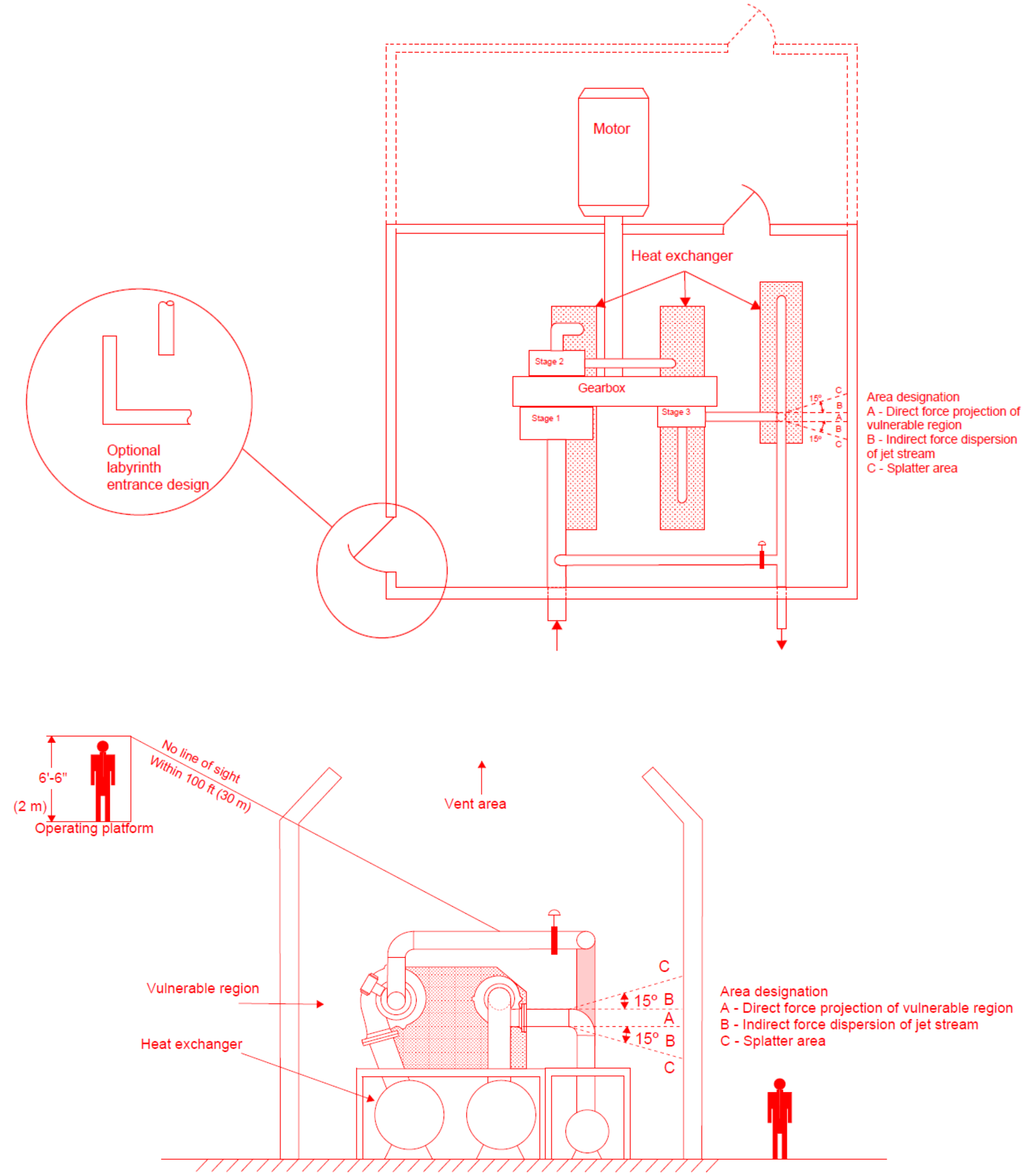



**Figure 5b—Example of an integrally geared centrifugal oxygen compressor impact force distribution on barrier (plan and front views)**

## 12.6 Safety barrier miscellaneous design features

### 12.6.1 Oxygen accumulation

Since oxygen is denser than air at the same temperature, it tends to accumulate in depressions or enclosed spaces. Trenches or pits should be avoided. When trenches are used inside the hazard area for cable routing, they should be filled with sand. The safety barrier shall be provided with sufficient ventilation to prevent a buildup of oxygen around the compressor. If the safety barrier is open topped, this is normally adequate. However, if it is enclosed, forced ventilation should be provided at the rate of not less than 6 air changes per hour.

#### 12.6.2 Nitrogen asphyxiation hazard

If the compressor has the capability for being test run on nitrogen or nitrogen is being used for the seal gas, an asphyxiation hazard can exist.

### 12.7 Location

#### 12.7.1 Compressor building

If the safety barrier is within a compressor building, the building design shall take into account the overpressure from the release of high pressure gas that can occur in the event of a fire.

#### 12.7.2 Safety of personnel and plant

Oxygen compressors should be located away from main walkways, normally occupied areas (especially elevated ones), and other hazardous or critical equipment. It is important that there are good and clear evacuation routes from the vicinity of the oxygen compressor installation.

#### 12.7.3 Erection and maintenance

The location shall be such that the equipment can be kept clean and dry during installation and maintenance. During the design phase, attention should be paid to the crane set up and equipment lay down areas that will be required for erection and maintenance. Different styles of compressor have different requirements.

#### 12.7.4 Overhead cranes

Precautions shall be taken to prevent oil or grease from overhead or mobile cranes entering the oxygen clean areas or contaminating the hazard area during erection, maintenance, and operation.

The layout should preclude the need for cranes to transit over operating oxygen compressors. If this is not possible, the cranes should be pendant operated and their movement and load strictly controlled. When not in use, the crane should be located away from the hazard area.

### 12.8 Fire protection and precautions

#### 12.8.1 Introduction

Once started, fires in oxygen compressors are nearly impossible to extinguish until all the contained oxygen gas is consumed in the fire or vented to atmosphere. While it is true that once the oxygen supply is cut off and the inventory reduced the actual oxygen fire will be over quickly, extensive damage is likely and sometimes other combustible material such as oil is ignited and continues to burn after the actual oxygen promoted fire is out. For these reasons, oxygen compressor systems shall be designed to minimise the initiation of any fires and to vent the oxygen inventory as quickly as possible in case of a fire or potential ignition. These are the most effective ways of reducing the chance of personnel injury and minimizing equipment damage.

Fire protection should also include a strict housekeeping policy, developing an emergency plan with local fire officials, and supplying appropriate firefighting equipment. The emergency plan should be reviewed periodically with local authorities.

#### 12.8.2 Isolation and quick venting systems

Isolation and quick venting of the oxygen inventory have been found to be the most effective methods of minimizing the extent of an oxygen fire. In case of a compressor trip due to an emergency, the primary consideration shall be to dump the oxygen inventory and isolate the compressor from the oxygen supply. The pressure in the entire compressor system should fall to 0.1 MPa (14.5 psi) in less than 20 seconds. To achieve this, automatic and quick operation of isolation and vent valves are required. A vent valve at an intermediate stage may be required in addition to the discharge vent valve.

#### 12.8.3 Flammable material

Bringing flammable materials into the hazard area should be avoided whenever possible. When this cannot be avoided, for example, during maintenance operations, any flammable materials brought into the hazard area should be removed before oxygen is introduced to the compressor. In the event of an oil spill or leak, the oxygen compressor should be shut down at the earliest opportunity, the leak repaired, and the oil cleaned up.

### 12.9 Protection of personnel

PPE requirements shall be in accordance with approved written procedures.

When a person has been in contact with an oxygen-enriched atmosphere, they shall not smoke or go near open flames, hot spots, or sparks until they have properly ventilated their clothes in a normal atmosphere. A ventilation period of not less than 15 minutes with movement of the arms and legs and with coats removed is recommended [14].

## 13 Erection and commissioning

### 13.1 Erection

#### 13.1.1 Responsibility

See Section 11.

The increased emphasis on packaged compressors means that the responsibility for the correct erection and the maintenance of cleanliness of the compressor system may well extend back to the manufacturer's and major sub-suppliers' works. The requirements of 11.3 apply to the cleanliness standards throughout the erection of the compressor unit. The designated person shall keep a chronological record showing who carried out the main assembly work and who took the "as built" measurements and carried out the testing. This applies even if the designated person came from another firm. An oxygen cleanliness log should also be maintained to record the time, person, and place that each part of the oxygen circuit, including the gas feeds to the compressor were approved as "clean for oxygen service". This log should also record the inspection method used, for example, ultraviolet (UV) light, solvent analysis, etc.

The compressor should remain the responsibility of the manufacturer until the provisional handing over has occurred. This normally takes place after a successful initial oxygen run.

#### 13.1.2 Clearances

All axial and radial clearances between stationary and rotating parts of the compressor shall be measured and the results recorded during preparation in workshop or during erection at site. Any out of tolerance measurements shall be reviewed and approved by the manufacturer and the user.

#### 13.1.3 Prevention of undue forces

To prevent excessive stress being imposed on the compressor, all joints shall be assembled and aligned in accordance with manufacturer's requirements. Flanges shall be parallel and correctly aligned. This requirement applies to each flange of the compressor and the pipework.

#### 13.1.4 Tools

The tools, appliances, and measuring devices used during installation and assembly of the compressor and auxiliary equipment that come into contact with oxygen shall be cleaned with a suitable cleaning agent. Tools used for the lubricating oil system or other parts of the machine shall not be used for components that come into contact with oxygen. [Only lint- cleaning cloths shall be used. When using lifting tackle, any contamination by oil from the ropes, gears, or other sources of lubrication shall be prevented.

#### 13.1.5 Hazard area

At an appropriate stage of erection, the hazard area shall be declared a clean area and access restricted to authorised personnel only. All personnel entering the clean area should wear clean shoes or overshoes and clean overalls without pockets. Personnel shall be instructed in the need for cleanliness.

#### 13.1.6 Oil flushing

Flushing of the lube oil system shall not be carried out unless the seal gas system and its associated interlocks with the lube oil system are fully functional. The lube oil system shall be checked for leaks during flushing. Flushing and leak detection can be improved by cycling the temperature of the oil.

#### 13.1.7 Foundation sealing

In order to prevent oil impregnation, the foundation of the compressor and associated equipment should be properly sealed prior to the commissioning of the lube oil system.

#### 13.1.8 Purging after assembly

Once the compressor has been closed up, an oil-free, dry, non-flammable gas purge shall be maintained in the compressor via the labyrinth seals and at other points (for example, coolers, piping, gaseous drain points) as necessary to ensure that a non-corrosive atmosphere is maintained in the machine.

### 13.2 Testing and commissioning

#### 13.2.1 Introduction

High energy costs, high site costs, and the ability of manufacturers to test complete compressor assemblies at full power and in their contract configuration has meant that in some instances the best option is to ship from the manufacturer's works as a complete, fully tested, oxygen clean compressor system. However, in other instances the best option is to site erect and site fabricate the compressor system.

The recommendations and requirements for testing have to be flexible enough to cope with widely different circumstances. For this reason, this publication stipulates what objectives the testing shall achieve, and the type of test and readings that shall be taken to meet the objective. It does not stipulate where and in what order the testing shall be done.

#### 13.2.2 General

Any instrumentation required for testing the machine, for example, pressure gauges, flow meters should only be used for this duty. When they are used on site, they shall be specifically cleaned and marked "FOR OXYGEN USE ONLY". All parts that are normally under pressure including the instrumentation, gas, and oil pipework shall be subjected to a pressure test, unless specified elsewhere in the publication. The type of test and test pressure shall be agreed between the manufacturer and the user.

#### 13.2.3 Demonstration and verification for oxygen service objectives

It is not permitted to put the compressor into oxygen service unless the following objectives have been achieved:

- Demonstration of the mechanical integrity of the complete compressor system over the predicted operating range;
- Verification of the rotor dynamic prediction and the stability of the rotor;
- Verification of the predicted thermodynamic performance;
- Functional demonstration of the instruments and controls;
- Verification that the compression system is clean for oxygen service;

- Verification of seal gas pressures to ensure proper operating conditions;
- Verification of no oil leaks;
- Verification of the atmospheric gap between the process gas seal and oil seal with an oil-free tell tale; and
- Verification of dry casing or packing vents.

#### 13.2.4 Demonstration of mechanical integrity

##### 13.2.4.1 Acceptable test conditions

For the test to be valid, it shall meet the following criteria:

- test gas—molecular weight 28 to 32;
- flow—as close to design as the test gas permits;
- suction pressure—design;
- speed—nominal design speed;
- discharge pressure—as close to design as the test gas permits; and
- duration of the test—minimum of 4 hours of continuous operation of maximum continuous speed with data trended or logged every 30 minutes.

##### 13.2.4.2 Tests to be carried out while on test gas

- surge test and verification of surge detection system;
- leak check of the flanged joints of all compressor casings, coolers, piping systems, instrument tubing, etc.; and
- visual leak check of lube oil system.

##### 13.2.4.3 Post test inspection

After the surge test, the compressor shall be opened and the seals and impellers inspected for rubs. Rubbing is not acceptable except in the seal area where by design it is permitted to happen (see 4.3.7).

#### 13.2.5 Verification of the rotor dynamics prediction and the stability of the rotor

##### 13.2.5.1 Acceptable test conditions

For the test to be valid, it shall meet the following criteria:

- test gas—molecular weight 28 to 32;
- flow—minimum to maximum;
- suction pressure—design;
- speed—minimum to maximum;
- discharge pressure—as close to design as the test gas permits (see NOTE);
- oil temperature—normal to maximum; and
- duration of the test—as required.

NOTE—To test the stability of the rotor, it may be required to run on a safe gas just below the relief valve set pressure or at a higher molecular weight to give an equivalent density.

#### 13.2.5.2 Test to be carried out

Refer to 4.4.2.

#### 13.2.5.3 Post test inspection

None planned as a normal part of the test.

### 13.2.6 Verification of the predicted thermodynamic performance

#### 13.2.6.1 Acceptable test conditions

The thermodynamic performance test shall be conducted in accordance with an internationally recognised standard. This could be in the manufacturer's works or on site but the acceptable conditions/instrumentation shall be agreed between the manufacturer and the user.

Site test using plant instruments. In this instance the acceptable conditions shall be whatever can be achieved during plant startup.

#### 13.2.6.2 Tests to be carried out

Operate the compressor at several suction throttle valve/guide vane settings stonewall to surge. Log flow, power, and stage temperatures and pressure so that the surge line and performance of the compressor can be compared with that predicted for the test gas being used.

The purpose of this test is to confirm that the compressor is operating satisfactorily. Plant instrumentation can be used for this test.

If the guaranteed thermodynamic performance of the compressor has to be validated, special test accuracy instruments are required and shall be agreed between the manufacturer and the user.

The tests can be carried out using dry, oil-free gas.

The surge test shall be carried out using dry, oil-free air, nitrogen, or other gas mixtures containing no more than 23.5% oxygen.

#### 13.2.6.3 Post test inspection

None planned as a normal part of this test.

### 13.2.7 Functional demonstration of the instruments

#### 13.2.7.1 Acceptable test conditions

No special test conditions are required to demonstrate the instrument controls so this can be done when the compressor is being run to achieve other test objectives.

#### 13.2.7.2 Tests to be carried out with compressor stopped

Put the breaker into the test position and start the compressor. This means that although the compressor is stopped as far as the protection and trip system is concerned, it appears to be running.

Carry out functional checks of the following:

- alarm and trips;
- all interlocks; and
- dump vent, anti-surge, and power operated isolation valves including the time to open or close.

It is assumed that all the instruments have already been calibrated and loop checked.

#### 13.2.7.3 Test to be carried out with the compressor running

- Check the function of the control and anti-surge system and surge detector; and
- Check the operation of the dump vent and isolation system and check that the discharge pressure falls to 0.1 MPa (14.5 psi) in 20 seconds.

#### 13.2.7.4 Post test inspection

None planned as a normal part of this test.

### 13.2.8 Verification that the compression system is clean for oxygen service

#### 13.2.8.1 Acceptable test conditions

The compressor shall be oxygen clean and fully completed in the final configuration.

#### 13.2.8.2 Tests to be carried out

Conduct a system blowout to clear any debris. This can be done by opening drain lines and vent lines and operating the dump system, which creates high flows in the system and ensures that any debris lying in areas of low velocity are dislodged before the compressor is put on oxygen.

#### 13.2.8.3 Post test inspection

Examine the suction filter, recycle valves, and valve diffusers (if any) with the potential for particulate contamination.

### 13.2.9 Test programme

The publication does not require any specific test programme provided that all the test objectives are achieved as defined in 13.2 and the test program shall be agreed on a case-by-case basis between the manufacturer and the user.

## 13.3 Commissioning on oxygen

### 13.3.1 Preparation for the initial run on oxygen

Before running the compressor on oxygen the designated person shall ensure that:

- All the test objectives have been met;
- The entire compressor system has been certified “clean for oxygen service”;
- There is satisfactory proof that the pipeline upstream of the compressor has been cleaned for oxygen service. This can be demonstrated by blowing through with dry, oil-free, air upstream of the filter at a velocity not less than normal operating velocity for a period of several hours. This blow through shall be vented upstream of the suction filter and as close to it as possible; and
- The hazard area is clean and free from all combustible materials and that the safety barrier that surrounds the hazard area is complete and fully functional.

### 13.3.2 Initial run on oxygen

When the compressor is running to the satisfaction of the designated person, the hazard area shall be cleared of all personnel and the access secured before introduction of oxygen. Oxygen should first be introduced to the running machine slowly over a period of at least 2 hours. During the startup and until establishment of constant operation, all indicating instruments should be monitored with special attention devoted to the gas pressures and temperatures and the vibration levels. The values indicated should be trended or logged at short intervals (approximately every 15 minutes). After approximately 4 hours of operation, readings may be taken and logged at hourly intervals.

# 14 Operation

## 14.1 General

Factors requiring specific attention in the operation of an oxygen compressor are as follows.

## 14.2 Combustible matter

Dust, oil, grease, and other forms of combustible matter readily ignite in oxygen.

## 14.3 Machine rubs

Rubs in a machine can cause ignition, due to localised high temperatures being generated.

## 14.4 Rotor/bearing instability

Rotor or bearing instability can cause large shaft deflection leading to dangerous rubs.

## 14.5 Machine vibrations

Machine vibrations due to misalignment, rotor unbalance, gearing defects, etc., can cause bearing failures, subsequently leading to rotor rubs.

## 14.6 Leaking cooler tubes

Leaking cooler tubes result in rusting in the casing, forming a dust nucleus for ignition.

## 14.7 Gas leakage hazard

Leakage and accumulations of gases can occur without operators being aware. Any source of open flame or ignition can cause a fire in operator's clothes that may be saturated with oxygen. Oxygen deficiency can cause asphyxiation.

## 14.8 Compressor surge

Surge is a cause of strong vibrations and excitation of the shaft and impellers that can lead to rubs and mechanical failure which in turn can cause a fire.

## 14.9 Machine protection systems

A change in levels such as vibration, axial position, pressures, temperatures, etc., should be investigated as soon as a change in levels is discovered.

## 14.10 Operational inspections

In addition to regular inspections of the centrifugal compressor, the following should also be performed:

- Centrifugal compressors equipped with tell tale vents between bearings and gas seal housings should be regularly checked for oil discharge. This can be accomplished by viewing through windows, by piping drains outside the barrier, or other means. Care shall be taken to ensure that lubricating oils do not come in contact with the oxygen being compressed; and

- Bearing chamber vents emit considerable oil vapour and atmospheric dirt settling on this oil film makes it difficult to determine whether or not oil leakage is present at the atmospheric vent checkpoints. These areas should be kept clean for safety and housekeeping reasons as well as to facilitate evaluation of a possible problem. Oil vapours should be directed away from the compressor area and any potential oxygen venting points. Any oil vapour piping should slope downward away from the bearing to avoid liquid oil accumulation in piping.

### 14.11 Responsibility transfer documentation

When the responsibility for the machine changes hands, for example, from commissioning to the operator, documentation is required confirming that the machine is in a suitable condition.

### 14.12 Qualifications and training for operating personnel

The operating personnel shall have training in compressor operation.

Knowledge of the machine construction is helpful to fully understand the importance of oxygen safety. Every opportunity should be given for operating personnel to maintain close liaison with experienced engineers.

### 14.13 Hazard area

If it is necessary to enter the hazard area for the analysis of defects when the machine is operating it shall first be changed over to dry, oil-free, air or inert gas. It should be noted that, in the vicinity of the hazard area, both oxygen enrichment and oxygen deficiency can occur due to, for example, leaking flanges or defective seal systems. The oxygen concentration shall be monitored to ensure that it is between 19.5% and 23.5%.

### 14.14 Fire drills

All personnel whose work is associated with an oxygen compressor installation should be instructed in the special hazards involved. The difference between fire in an oxygen-enriched atmosphere (greater than 23.5% oxygen) and fire in ordinary air should be emphasised. The person in charge in the event of an incident should be known. Instructions should be augmented by frequent drills so action can be taken immediately on the occurrence of a hazard condition. The local firefighting authority should also be aware of these considerations (see 12.8).

### 14.15 Emergency purge and vent systems

If an emergency inert purge system that may be operated from pressurised storage systems is installed, it should be regularly checked to ensure that adequate gas supplies are available.

### 14.16 Record of machine operation

Baseline operating parameters of the compressor shall be established. A record of operating parameters shall be kept. Deviations from baseline operating parameters shall be identified either automatically in the monitoring system or by manual logs and shall be resolved.

### 14.17 Tripping devices

#### 14.17.1 Operating checks

The operation of tripping devices, control valves, and check valves should be checked on routine shutdowns, by actuating such trips, valves, etc., where this can be done without affecting the safety of the machine and/or installation.

#### 14.17.2 Trip override

Permanent trip overrides shall not be used. Temporary override is allowed during startup sequences and other exceptional circumstances provided that such situation is supervised and agreed. When a machine is shut down by one of its protective trip functions, it shall not be restarted until the reasons have been fully investigated.

### 14.18 Interlock systems

Operators shall be familiar with the principles and operations of any interlock system installed.

### 14.19 Oil filters

Routine monitoring of oil filters pressure drop shall be conducted. All oil spillage should be thoroughly cleaned up immediately and prevented from spreading.

### 14.20 Startup procedures

Startup procedures shall be established consistent with the condition of the compressor. Startup procedures may need to be modified if the compressor is in a degraded condition. For the start of a new compressor or restart of a compressor after modifications or maintenance, a more thorough check is required than a compressor undergoing a routine restart.

Safety barrier doors can be kept open while operating on inert gas or dry, oil-free air. Before switching to oxygen, ensure that no personnel are within the safety barrier confines. All safety barriers shall be in place and secured before oxygen is introduced.

Routine operation of an oxygen compressor can require shutdown and subsequent restart as a normal procedure. On normal shutdowns and startups with oxygen, the number of personnel in the area should be kept a minimum. The decision as to whether to start up directly on oxygen or on dry, oil-free, air or inert gas after a normal shutdown shall be taken by the user based on a risk assessment, for example, taking into consideration operating pressure and machine type.

There shall be no startup of a machine after a trip without a pre-established procedure. When the unit has tripped due to a malfunction or its protection system, the cause of the shutdown shall be determined and rectified before starting.

Dry, oil-free, air or inert gas shall be used for startup on the following occasions:

- startup of a new machine after erection;
- startup of a machine after maintenance of the following type:
  - maintenance that has necessitated the purging of the machine with dry, oil-free, air or inert gas;
  - replacement of bearings;
  - resetting of the anti-surge control system; and
  - startup of a machine after prolonged standstill.

Dry, oil-free, air or inert gas or oxygen is permissible for startup on the following occasions:

- startup as a normal procedure after a planned shutdown;
- startup of an operational stand-by machine previously on oxygen service; and
- startup of a machine after maintenance, except the types of maintenance in the previous list items in this subsection.

## 15 Maintenance

### 15.1 General

#### 15.1.1 Method

Because of the possible consequence of a breakdown while in oxygen service, a centrifugal compressor should be maintained to the highest possible standards. To achieve these standards, maintenance personnel shall be trained and records should be kept of all maintenance work undertaken.

The frequency and content of maintenance work should be defined by the user based on operating experience and manufacturer's recommendation. Monitoring of the running data is important in ensuring reliable operation of the compressor. This data can be used as an input in establishing the period between major overhauls.

It is not possible to state a precise period between major overhauls that covers all circumstances. The period will depend upon the following:

- manufacturer's recommendations;
- number of hours run;
- number of starts since the last overhaul; and
- previous operating behaviour and history.

It is recommended that the manufacturer be involved in major maintenance or repair work. The requirements and standards covered in Section 13 shall be complied with.

In addition to routine maintenance work, particular attention shall be paid to centrifugal compressors that have been operated beyond their design life. Experience shows that casted components can exhibit emerging inclusions, cracks, or porosities during non-destructive testing (i.e., dye penetrant testing) that were not present during original manufacture.

NOTE—It has been noted that a number of fires have occurred immediately after overhauls. Therefore, it is recognised that internal inspections could also be the cause of an increased risk.

#### 15.1.2 Compressor isolation

In addition to the normal requirements for isolation that exist when conducting major maintenance on compression equipment, oxygen compressor maintenance requires that consideration be given to the hazards presented by an oxygen-enriched atmosphere and by an oxygen-deficient atmosphere. An oxygen-deficient atmosphere is due to the potential venting of nitrogen seal and purge gas into the work area. Before the work is performed, the compressor shall be mechanically and electrically isolated, isolated from the process, and depressurised and purged on both the suction and discharge sides of the compressor. Isolation shall include the main process stream, purge supplies, and seal gas. The preferred method of gas isolation is the use of double block and bleed valves or piping blinds. When the isolation has been completed, the equipment shall be surveyed with a portable oxygen analyser to verify that the isolation has been successful and no oxygen or nitrogen leakage is occurring. The atmosphere should have an oxygen content between 19.5% and 23.5% before any further work takes place. If any leakage is detected, a blind or plug shall be installed. Compressor driver lockout is mandatory.

#### 15.1.3 Lock out/tag out procedure

The implementation of a formal lock-out and tag-out (LOTO) procedure is required before working on any equipment. A safe work permit procedure shall be applied when maintenance or repair is performed on the compressor or for any other work in the hazard area.

#### 15.1.4 Functional test

The correct operation of the compressor trip system and the dump and isolation valves is an important contributor to the safe operation of oxygen compressors. In order to ensure correct operation, all the components should be recalibrated and the system should be subjected to a full functional test at least once every 3 years.

### 15.2 Cleanliness during maintenance

#### 15.2.1 Exterior cleaning

The exterior of the oxygen compressor should be inspected and cleaned, if necessary, before disassembly to prevent dirt from entering areas that will be opened. The coolers need not be cleaned before the work, except if coolers are disassembled. The exterior of the coolers should be included in the final wash as the cleaning of components above the coolers could allow runoff to contaminate these areas.

#### 15.2.2 Interior cleaning

During maintenance of the compressor the standards of cleanliness specified in 11.3 shall be observed. Clean, white, lint-free gloves and clean, white overalls should be worn while assembling oxygen clean components to avoid contaminating the parts with dirt, grease, or oil. All tools and lifting devices shall be cleaned before use on oxygen equipment to avoid contamination.

### 15.3 Rotor checks

#### 15.3.1 Compressor open for overhaul

If the compressor is opened for overhaul or inspection, the impellers should be inspected for cracks provided that cleaning and cleanliness is performed and controlled.

#### 15.3.2 Check balance of spare rotors

Spare rotors should be subjected to a check balance before installation. This precaution is important for rotors that have been in storage for more than 1 year.

### 15.4 Startup after maintenance

Startup of a compressor after major maintenance work needs the same level of close inspection and monitoring as that of a new compressor. See 13.3.

#### 15.4.1 Vibration levels

After major maintenance or inspection of oxygen compressors, new startup and steady state vibration levels should be evaluated during inert gas or dry, oil-free air operation

Personnel may perform vibration analysis while the compressor is operating on oxygen by using connections outside of the safety barrier.

### 15.5 Spare parts

#### 15.5.1 Manufacturer replacements

Replacements for all parts originally manufactured by the machine manufacturer should be purchased from the manufacturer. All other replacement parts should be in accordance with the manufacturer's specification. It is also essential that any internal parts replaced shall be oxygen cleaned.

#### 15.5.2 Oxygen components

All components that come into contact with oxygen gas shall be preserved as specified in 11.4. Balancing certificates, etc., included with spare rotors shall be transferred to the operator's maintenance records when a change of rotors takes place.

## 16 Instruction manual

### 16.1 General

The instruction manual shall highlight the specific safety aspects in operating and maintaining oxygen compressors and the need for a high standard of cleanliness.

### 16.2 List of minimum information

The instruction manual shall contain the following information as a minimum:

- compressor design data and performance characteristics including the surge line
- description of the following items, placing emphasis on the details that are special for oxygen service:
  - compressor
  - lube oil system and frequency of oil check
  - seal system
  - controls and instrumentation with set points of alarms and trip
  - associated equipment
  - installation;
- operation with startup, shutdown, and restart procedures to safeguard the compressor;
- maintenance with disassembly and assembly procedure and spare parts stocking conditions;
- protection of the compressor unit during prolonged standstill;
- list of materials of construction;
- overall drawing with seal and bearing clearances and tolerances;
- trouble shooting guide; and
- list of special tools for maintenance.

### 16.3 Additional Information

Information that shall be supplied but which may be separate from the instruction manual:

- detailed list of the spare parts with sectional view, subject, and reference numbers;
- records of balancing and overspeed tests;
- records of crack tests of the impellers; and
- records of all the tests carried out by the manufacturers.

## 17 References

[1] CGA P-11, *Guideline for Metric Practice in the Compressed Gas Industry,* Compressed Gas Association, Inc. www.cganet.com

[2] EIGA Doc 147, *Safe Practices Guide for Cryogenic Air Separation Plants,* European Industrial Gases Association, Inc. 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 harmonised regional references.

[3] API Standard 617, *Axial and Centrifugal Compressors and Expander-compressors,* American Petroleum Institute. www.api.org

[4] M034-1, *List of nonmetallic materials compatible with oxygen by BAM Federal Institute for Materials Research and Testing*, BAM Federal Institute for Materials Research and Testing. www.bgrci.de

[5] ASTM G63, *Standard Guide for Evaluating Nonmetallic Materials for Oxygen Service,* ASTM International. www.astm.org

[6] NEMA SM 23, *Steam Turbines for Mechanical Drive Service,* National Electrical Manufacturers Association (NEMA). www.nema.org

[7] ISO 1940-1, *Mechanical vibration — Balance quality requirements for rotors in a constant (rigid) state — Part 1: Specification and verification of balance tolerances,* International Organization for Standardization (ISO). www.iso.org

[8] ISO 10816, *Mechanical vibration — Evaluation of machine vibration by measurements on non-rotating parts — Part 1: General guidelines,* International Organization for Standardization (ISO). www.iso.org

[9] EIGA Doc 13, *Oxygen Pipeline and Piping Systems,* European Industrial Gases Association, Inc. 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 harmonised regional references.

[10] EIGA Doc 154, *Safe Location of Oxygen and Inert Gas Vents,* European Industrial Gases Association, Inc. 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 harmonised regional references.

[11] EIGA Doc 33, *Cleaning of Equipment for Oxygen Service,* European Industrial Gases Association, Inc. 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 harmonised regional references.

[12] API Standard 614, *Lubrication, Shaft-sealing, and Oil-control Systems and Auxiliaries,* American Petroleum Institute. www.api.org

[13] API Standard 670, *Machinery Protection Systems,* American Petroleum Institute. www.api.org

[14] CGA P-45, *Fire Hazards of Oxygen and Oxygen-Enriched Atmospheres,* European Industrial Gases Association, Inc. 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 harmonised regional references.