CAGI B19.1-2011
(Supersedes ASME B19.1-1995)

SAFETY STANDARD FOR AIR COMPRESSOR SYSTEMS

CAGI B19.1-2011

Compressed Air & Gas Institute

Sponsor

Compressed Air & Gas Institute
1300 Sumner Ave
Cleveland, Ohio 44115-2851

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(Supersedes ASME B19.1-1995)

COMPRESSED AIR & GAS INSTITUTE
Safety Standard for Air Compressor Systems

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CAUTION NOTICE:

This standard may be revised or withdrawn at any time. CAGI endeavors to review standards on a five-year cycle to determine whether standards should be reaffirmed, revised, or withdrawn.

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Suggestions for improvement of this standard will be welcome. They should be sent to the Compressed Air & Gas Institute.

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Foreword

(This Foreword is not a part of the CAGI Standard *Safety Standard for Air Compressor Systems,* CAGI B19.1-2011).

This Standard is developed and published by the Compressed Air & Gas Institute. This Standard is intended to serve as the basis for state, municipal, and other jurisdictional authorities in drafting regulations to safely design, install, operate, and maintain compressor systems.

Safety codes and standards are intended to enhance public health and safety. Revisions result from committee consideration of factors such as technological advances, new data, and changing environmental and industry needs. Revisions do not imply that previous editions were inadequate.

It should be pointed out that governmental jurisdiction(s) may have authority over any particular installation. Inquiries dealing with problems of a local character should be directed to the proper authority of such jurisdiction(s). It is recommended that, prior to adoption, all pertinent state and local laws or ordinances be reviewed and where there is a conflict with any of the requirements of this Standard an exception to such conflicting requirement be noted, quoting the section of the law which applies.

Equipment covered by this Standard was originally incorporated in the ASME B19.1-1995 Standard. The CAGI Rotary Positive Section reviewed the ASME standard, revised it where appropriate.

Comments intended to improve this standard are welcomed and should be submitted to CAGI.

CAGI STANDARD
B19.1-2011
Safety Standard for Air Compressor Systems

Section 1 – General

1.1 Scope
This Standard addresses all aspects of air compressor systems from the entrance to the inlet device through the compressor and associated heat exchangers, dryers, and pulsation suppression devices to the point of entry to the distribution system.

The following types of air compressor systems are specifically excluded from this Standard:
(a) Those having ratings of 5 psig (0.34 bar gage) or less differential pressure. This eliminates fans and low pressure blowers, but includes mechanical air vacuum pumps.
(b) Those having drivers rated at less than 1 ½ horsepower (1.1 kW).
(c) Those which operate as part of facilities for processing petroleum, petrochemicals, or chemicals, including air separation plants.
(d) Those functioning as part of automotive and transportation equipment. Examples are truck air brake systems, aircraft air conditioning systems, and automotive emission control compressors.
(e) Thermal compressors such as steam jet ejectors.
(f) Turbochargers and superchargers that are part of a prime mover.

1.2 Purpose
This Standard classifies and makes available general information on practices, specific requirements, and recommendations covering safety for air compressors, their drives, and auxiliaries. Safety requirements, recommendations, and suggestions described in this Standard provide guidance to those who design, produce, install, maintain, and/ or operate air compressor systems.

The general subject of compressed air is extremely broad. It is the intention of this Standard to cover safety in all aspects of the generation of compressed air.

1.3Application
The provisions of this Standard apply to air compressor systems except as excluded below. Other exceptions may be necessary with regard to systems of unusual design, complexity, or function. In such cases, the system designer has the responsibility to develop equivalent safety features.

This Standard does not apply to the following:

(a) Basic mechanical design. This Standard assumes as essential that the compressor and air compressor system components be designed by qualified engineers in accordance with recognized standards and specifications.
(b) Design and operation of the equipment or apparatus which uses the compressed air.

(c) Air compressor systems that are an integral part of facilities for processing petroleum, petrochemicals, or chemicals, including air separation plants. These are covered by ASME B19.3, Safety Standard for Compressors for Process Industries.

The principles promoting safe generation and use of compressed air are not restricted to new air compressor systems. It is recommended that all air compressor systems be reviewed to consider possible changes due to revision of this Standard.

1.4 Definitions

aftercooling - involves cooling of air in a heat exchanger following the completion of compression to reduce the temperature and to liquefy condensable vapors

capacity - the inlet volumetric flow rate

compressor - the principal types of compressors are defined below. Cam, diaphragm, and diffusion pumps or compressors are not shown because of their specialized applications and relatively small size

compressor, axial - a dynamic machine in which air acceleration is obtained by the action of the bladed rotor. Main air flow is axial.

compressor, centrifugal - a dynamic machine in which one or more rotating impellers, usually shrouded on the sides, accelerate the air. Main air flow is radial.

compressor, dynamic - a rotary continuous flow machine in which the rapidly rotating element accelerates the air as it passes through the element, converting the velocity head into pressure, partially in the rotating element and partially in stationary diffusers or blades.

Compressor, helical or spiral lobe - a rotary positive displacement machine in which two intermeshing rotors, each with a helical form, compress and displace the air.

compressor, liquid piston - a rotary positive displacement machine in which water or other liquid is used as the piston to compress and displace the air handled.

compressor, mixed flow - a dynamic machine with an impeller form combining some characteristics of both the centrifugal and axial types.

compressor, positive displacement - a compressor in which successive volumes of air are confined within a closed space and elevated to a higher pressure.

compressor, reciprocating - a positive displacement machine in which the compressing and displacing element is a piston having a reciprocating motion within a cylinder.

compressor, rotary positive displacement - a machine in which compression and displacement is effected by the positive action of rotating elements.

compressor, sliding vane - a rotary positive displacement machine in which axial vanes slide radially in a rotor eccentrically mounted in a cylindrical casing. Air trapped between vanes is compressed and displaced.

compressor, thermal (also *known as ejector)* - a device that uses a high velocity air or steam jet to entrain the inflowing air, then converts the velocity of the mixture to pressure in a diffuser.

compressor, two impeller straight-lobe - a rotary positive displacement machine in which two straight mating lobed impellers trap air and carry it from intake to discharge. There is no internal compression.

discharge pressure - the air pressure at the discharge flange of the compressor

discharge temperature - the air temperature existing at the discharge flange of the compressor.
NOTE: In a multistage compressor, the various stages will have different discharge pressures and temperatures.

gage pressure - force per unit area as determined by most instruments, gages, and manometers. It is defined as absolute pressure minus barometric pressure.

heat - energy transferred because of a temperature difference.

horsepower - the unit of power equal to 33,000 fl-lb of work per minute (l hp = 746 W).

hydrostatic test pressure - the pressure above the maximum allowable working pressure to which the manufacturer has tested a component.

inlet pressure - the lowest air pressure in the inlet piping to the compressor.

inlet temperature - the air temperature at the inlet flange of the compressor
NOTE: In a multistage compressor, the various stages will have different inlet pressures and temperatures.

intercooling - the cooling of air between stages of compression to reduce the temperature, to reduce volume to be compressed in the succeeding stage, to liquefy condensable vapors. or to save energy.

maximum allowable discharge temperature - the temperature determined by the manufacturer at the maximum discharge pressure at which the compressor can be continuously operated.

maximum allowable working pressure - the maximum pressure for which the manufacturer has designed the compressor, (or any part to which the term is referred, such as an individual cylinder or casing), when handling the specified gas at the specified temperature.

maximum continuous speed - the highest speed at which the manufacturer's design will permit continuous operation with overspeed and governor mechanisms installed and operating.

normal discharge temperature - the temperature of the air leaving the compressor (or a stage of the compressor) when the compressor is in good operating condition and all utilities and ambient conditions are as designed.

rated input power - the power at the rated capacity and the specified inlet temperature and pressure and discharge pressure.

surge point - the capacity below which operation becomes unstable at the operating speed of a centrifugal or axial compressor.

vacuum pumps - compressors with inlet pressure more than 1 psi (0.1 bar) below ambient atmospheric pressure.

1.5 References
This Standard is supplemented by the following Standards. Since revisions in and additions to these other Standards do occur, the edition bearing the latest date of issue shall be used. It is expected that best current practice will prevail.

The following Standards shall, to the extent specified herein, form a part of this Standard:

ANSI - American National Standards Institute
    Z535.2, Standard for Environmental and Facility Safety Signs

AMT – Association for Manufacturing Technology
    ANSI/AMT B15.1, Safety Standard for Mechanical Power Transmission Apparatus

API - American Petroleum Institute
    618, Reciprocating Compressors for General Refinery Services

ASME - The American Society of Mechanical Engineers
    A13.1, Scheme for Identification of Piping Systems
    ASME Boiler and Pressure Vessel Code, Section VIII, Division 1.

CGA - Compressed Gas Association
    G-7.1, Commodity Specifications for Air

ISO - International Organization For Standardization,
    R508, Identification Colours for Pipes Conveying Fluids in Liquid or Gaseous Condition in Land Installations and on Board Ships
    1940, Mechanical vibration -- Balance quality requirements for rotors in a constant (rigid) state -- Part 1: Specification and verification of balance tolerances

NEMA - National Electrical Manufacturers Association
    ICS-l, General Standards for Industrial Control and Systems
    ICS-2, Industrial Control Devices, Controllers, and Assemblies

MG-l. Motors and Generators
MG-2, Safety Standard for Construction and Guide for Selection, Installation, and Use of Electric Motors and Generators

NFPA - National Fire Protection Association
NFPA 70, National Electrical Code
NFPA 70B, Electrical Equipment Maintenance
NFPA 70E, Electrical Safety Requirements for Employee Workplaces

OSHA - Occupational Safety And Health Administration
Title 29, CFR Part 1910, Occupational Safety and Health Standards

The following additional Standards are valuable references:

ANSI B935, Practice for the Use of Fire-Resistant Fluids for Industrial Hydraulic Fluid Power Systems
ANSI B95.1, Terminology for Pressure Relief Devices
ANSI CSO.1O, General Requirements for Synchronous Machines
ANSI/IEEE 43, Recommended Practice for Testing Insulation Resistance of Rotating Machinery
ANSI/IEEE 56, Guide for Insulation Maintenance of Large Alternating-current Rotating Machinery (10 KVA and Larger)
ASME Guide SI-l, Orientation and Guide for Use of SI (Metric) Units
ASTM E 380, Metric Practice Guide
ISO R226, Normal Equal-Loudness Contours for Pure Tones and Normal Threshold of Hearing Under Free Field Listening Conditions
ISO 7010, Safety colours and safety signs
ISO 2151, Acoustics - Noise test code for compressors and vacuum pumps - Engineering method (Gr. 2)
UL 508, Electric Industrial Control Equipment
UL 873, Electrical Temperature-Indicating and Regulating Equipment
UL 900, Test Performance of Air Filter Units

1.6 Format
The mandatory rules of this Standard are characterized by the use of the word "shall". If a statement is of an advisory nature, it is indicated by the use of the word "should", or is stated as a recommendation.

1.7 SI (Metric) Units
This Standard contains SI (metric) units as well as customary units. The SI units in the text have been directly (soft) converted from the customary units. Further information on the use of SI units is contained in ASME 380, Metric Practice Guide, and ASME Guide SI-1, Orientation and Guide for Use of SI (Metric) Units.

Section 2 - Requirements and Recommendations Applying to All Air Compressor Systems

2.1 Design and Installation

2.1.1 Piping.
Color coding or other marking of piping systems is recommended. Piping system markings shall comply with OSHA Section 1910.144 and 1910.145. Coding to ANSI/ASME A13.l, ISO R508, or labels identifying line contents are preferred.

Foreign material (dirt, weld splatter, oil residue, rust, and debris) shall be eliminated from the intake line before startup.

The potential for discharge line fires can be minimized by reducing or eliminating the lubricating oil in the discharge line.

Piping exposed externally to corrosive conditions should be adequately protected for the conditions involved. Protective coatings should be inspected at regular intervals.

Deviations from manufacturer's recommendations will often result in reduced performance. The wrong length or size of inlet, interstage, or discharge line can create problems. When furnished, manufacturer's recommendations regarding piping should be followed unless a conflict exists with a duly appointed authority or prior standard.

2.1.1.1 Pressure Pulsations. Pulsation-induced vibration shall not cause a cyclic stress level in excess of the endurance limit of the material used.

Due to the pulsating nature of the flow of air through positive displacement compressors, it is possible that piping systems can experience excessive pressure pulsations where acoustic frequencies are close to the exciting frequency of the compressor. Such pulsations can cause:

(a) compressor driver to be severely overloaded;
(b) piping to vibrate with overstress occurring at fittings, valves, and structural supports;
(c) noise;
(d) vibrations in surrounding structures;
(e) damage to compressor valves;
(f) reduced capacity and performance.

Methods commonly used to correct pulsations include but are not limited to the following:

(a) commercial pulsation damping devices;
(b) strategically located orifices and/or choke tubes;
(c) volume bottles;
(d) a change in pipe length to avoid acoustic resonance.

Improved performance can be obtained by minimizing pulsation levels in the compressor and associated piping systems.

2.1.1.2 Valves. The type of shutoff valve used shall be selected with consideration given to the effects of pulsation. Generally, plug or ball valves are recommended for pulsating flow.

2.1.1:3 Piping Supports

(a) Pipe supports and stays shall be spaced to avoid resonance of the piping with the compressor.
(b) Piping anchors and supports shall be arranged to limit the forces and moments exerted on the air compressor system components to values recommended by the manufacturer. taking into account thermal expansion of piping.
(c) Piping systems should include supports, as required, to minimize vibration and stress at fittings and valves.

2.1.2 Drainage.
Areas and locations within the air compressor system that collect liquids shall be provided with valved drain connections so designed that accumulations can be removed and observed without danger to the operator or maintenance personnel. Such areas include intercoolers, aftercoolers, pulsation control vessels, separators, traps, receivers, jackets, and low points in the piping.

Small pipe-tapped drainage connections are subject to thread wear and pull-out, particularly in cast iron parts.

Drainage pipe should be designed to avoid undue vibration or potential breakage from accidental contact. Heavy wall pipe is recommended to avoid mechanical damage. Drainage receptacles, if not of the open type, shall be capable of withstanding the maximum pressure of the system to which they are connected.

Minimum drain size in cast iron parts should be as follows:

Driver Power, hp	**Minimum Size**
1½ through 15 (1.1 through 11.2 kW)	¼ NPT
Over 15 (11.2 kW)	½ NPT

Minimum drain size in malleable iron, ductile iron, or steel should be 1/4 NPT.

In all cases, the opening size should be such as to preclude bridging or plugging by contaminants.
Those areas subject to freezing shall be reviewed for complete drainage.

2.1.3 Overpressure Protection.
In any case where it is possible for
(a) the compressor or driver to cause overpressure,
or
(b) an external or internal fire to cause overpressure.

The system shall be protected by pressure relief devices. These devices shall prevent pressure in the weakest system component from exceeding 110% of the maximum allowable working pressure for that weakest component.

The maximum pressure setting of relief devices shall adhere to the requirements of UG-133 of the ASME Boiler and Pressure Vessel Code, Section VIII, Division 1.

Sizing of relief valves shall be in accordance with the formula given in UG-131 of the ASME Boiler and Pressure Vessel Code, Section VIII, Division 1.

Shutoff valves or restrictions shall not be installed between the pressure relief device and the system being protected.

Suitable pressure relief devices include spring loaded valves (see ASME Boiler and Pressure Vessel Code, Section Division 1, UG-l26) and rupture disks (see ASME Boiler and Pressure Vessel Code, Section VIII, Division 1, UG-127).

Manufacturer's data and instructions should always be followed.

Lines connecting the system being protected and the pressure relief device shall have a flow area at least as great as the flow area of the pressure relief device.

Relief device outlet lines shall be no smaller than the relief device outlet size and shall not be restricted in any way.

Short outlet lines with a minimum of fittings should be used. Elbows should be long radius.

Valves shall not be installed in relief device outlet lines.

Relief device outlet lines shall be so designed and installed as to preclude the collection of liquid at any point in the flow stream. They should be so located that effluent streams can be observed conveniently.

Relief devices shall have their outlet lines designed to preclude movement, shall be directed away from possible operator positions, and shall be directed to a safe point of discharge.

Relief valve and piping shall be adequately supported where the exit reaction forces would cause excessive motion or vibration.

2.1.4 Overtemperature Protection.
Compressors over 15 hp (11.2 kW) and with a discharge pressure over 50 psig (3.4 bar gage) shall be fitted with high discharge temperature shutdown devices located within 4 pipe diameters downstream of each discharge connection with the temperature sensing element in the main hot air stream. The devices shall be located as follows:

Compressor Type	Shutdown Sensor Location
Non-intercooled positive displacement	Compressor discharge
Air intercooled	Before each cooler and at compressor discharge
Liquid intercooled	Before each cooler and at compressor discharge

High temperature shutdown devices shall have a maximum shutdown setting of 50°F (28°C) above the normal discharge temperature.

This overtemperature setting is maximum and, in many cases, should be reduced. It takes into account the heat dissipating capabilities of the normal system. (Normal discharge temperature should be obtained from initial operation or from the compressor manufacturer.) Overtemperature shutdown devices shall positively stop all energy input to the system and should be the manual reset type. An alarm set at a lower temperature than the shutdown device should precede the overtemperature shutdown device. In those instances where a compressor shutdown would create a more hazardous condition than overtemperature, an alarm set at a lower temperature shall precede the shutdown device.

(a) Overtemperature - Water Cooled Engines.
Water cooled engines shall be provided with a high liquid temperature shutdown device. In those instances where an engine shutdown would create a more hazardous condition than overtemperature, an alarm set at a lower temperature shall precede the shutdown device.

(b) Overtemperature - Combustion Gas Turbines.
Combustion gas turbines shall be provided with a high gas temperature shutdown device set at the manufacturer's stated upper temperature limit. In those instances where a turbine shutdown would create a more hazardous condition than overtemperature, an alarm set at a lower temperature shall precede the shutdown device.

2.1.5 Inlet Systems.
All compressor systems shall be provided with inlet systems that will prevent entry of foreign material larger than can be ingested by the compressor and the remainder of the air compressor system without damage to either.

Air compressor systems using compressors with sliding, rubbing, or rolling contact should be fitted with high efficiency air filters to avoid high temperatures resulting from open clearances caused by excessive wear. The use of filter pressure drop indicators is recommended.

Inlet systems shall be so installed or located as to preclude entry into the air compressor system of toxic or flammable fumes or gases. Inlet systems shall be installed, located and/or guarded so as to preclude the possibility of catching and holding personnel or clothing. The inlet system should be capable of withstanding the full inlet pressure difference (usually vacuum) that can be generated by the compressor, or be protected by a differential pressure shutdown device.

The location and design of the compressor shall be considered in the location of the compressor inlet so as to prevent damage to the surroundings. When pulsating or large flows are involved, consult with manufacturers regarding their effects on large flat surfaces such as walls, doors, windows, ceilings, and roofs.

2.1.6 Protective Guards.
All exposed moving parts shall be provided with personnel protection guards. These guards shall be designed and constructed so as to avoid risk of injury to personnel. Moving parts are defined as those having movement that is not hand powered and which move during normal operation.

Guards shall comply with ANSI/AMT B15.1. Guards shall be made of sufficient materials, with or without a liner, when necessary to meet the area classification as defined by NFPA 70 and/or similar governing document.

Guards shall be securely fastened to the machine supporting structure or to the machines themselves.

Guard construction shall be such that heat buildup or concentration of corrosive materials will not adversely affect the parts being guarded or personnel.

2.1.7 Bearing Lubrication System Protection.
Air compressor systems having power input exceeding 30 hp (22.4 kW) should be provided with shutdown devices in each lubrication system to protect against loss of bearing lubrication. Consideration should also be given to installing loss of lubrication protection devices on systems having power input of 30 hp (22.4 kW) and less.

Rotary oil flooded screw compressors are excluded from this requirement because the high discharge temperature device performs this function on rotary oil flooded screw compressors.

The shutdown system should be designed and installed in such a manner that a simulated low lubricant pressure, flow, or differential pressure test may be safely made while the compressor is in operation. An alarm, set at a pressure or flow higher than the shutdown setting, should be included.

2.1.8 High Temperature.
External surfaces subject to temperatures in excess of 175 °F (80 °C) with which personnel may have contact shall be guarded or insulated. When guarding is not possible there shall be an adequate warning or a symbol.

2.1.9 Primary Safety Controls

2.1.9.1 Overspeed. Compressor drivers, except as covered below, shall be equipped with an overspeed shutdown which positively stops all energy input to the system if the system overspeeds for any reason. This overspeed shutdown shall be independent of any other governing or regulating apparatus. The overspeed shutdown shall be of the manually reset type with provision for manual tripping. Exceptions are as follows:

(a) diesel and gasoline engines having fuel flow limiting devices known to limit the maximum speed to 100% of designed rated speed of the limiting machine when the engine is unloaded;
(b) line frequency operated synchronous or induction alternating current electric motors;
(c) gas generator sections of gas turbines where they are proven to be speed-limited by design.

Manufacturer's recommendations on speed setting of the overspeed governor should always be followed. In the absence of recommendations, the following settings are suggested:

Driver Type	**Trip Speed as a Percentage of Rated Speed of Limiting Machine**
Steam Engine	110
Steam Turbine	110
Gasoline Engine	120
Natural Gas Engine	110
Combustion Gas Engine	105
Diesel Engine	110
Energy Recovery Expander	105

The overspeed shutdown device shall be tested regularly and should be tested at least on an annual basis. Three consecutive tests of the device should be conducted to ensure repeatability of the overspeed setting.

2.1.9.2 Isolating Valves. Isolating, fuel, steam, or energy source valves shall provide tight shutoff and shall be arranged to close automatically on shutdown of the driver. Fuel lines between the isolating valve and gas turbine shall be vented or drained automatically on shutdown of the turbine.

Internal combustion engines and gas turbines shall be provided with a block valve at a readily accessible location in the main fuel supply to the engine.

2.1.9.3 Reverse Rotation. Any compressor which can be rotated by reverse air flow shall be provided with a check valve or mechanical device which prevents such rotation. Positive displacement compressors employing automatic valves have built in check valves; therefore, additional check valves are not normally required; however, they should be considered. Undamped flapper-type check valves are not recommended. If a separate discharge check valve is used, it shall be downstream of any compressor overpressure protection relief device. An exception is made for oil flooded compressors, in which the check valve is normally located immediately adjacent to the discharge to minimize oil logging and reverse rotation

2.1.10 Secondary Safety Controls.

2.1.10.1 Speed Limiting. Compressor systems with power input greater than 7 1/2 hp (5.6 kW) that are driven by variable-speed drivers shall be fitted with a governing system having a maximum speed limit. The maximum speed setting of these governors should be such that mere removal of the compressor load does not cause the overspeed governor to trip.

Two-shaft gas turbines shall be provided with governing or protective systems having a maximum speed limit for each shaft.

2.1.10.2 Discharge Pressure Control. All compressors having operating characteristics that would permit a system overpressure shall be fitted with a discharge pressure control system, which in normal operation controls the compressor delivery capacity to prevent operation of the overpressure relief device.

Typical acceptable pressure control systems for 100 psig (6.9 bar gage) operation include:

- *(a) Constant Speed Drives*
  - *(1) Reciprocating Compressors*
    - (a) suction throttling
    - (b) discharge venting
    - (c) suction valve unloading
    - (d) combinations of suction valve unloading and clearance control
  - (2) *Rotary Positive Displacement Compressors.* Various combinations of suction throttling and discharge venting as controlled by maximum temperature or torque limits.
  - (3) *Dynamic Compressors.* Various combinations of suction throttling, variable guide vanes, and discharge venting as controlled by surge limit or maximum temperature.
- (b) *Variable Speed.* Vary the governor speed as needed under action of the system pressure.
- (c) *Automatic Start/Stop Control* Pressure cycles between upper and lower set points.

2.1.10.3 Antisurge Control. An antisurge device shall be used if system requirements indicate that the compressor may operate in surge for extended periods.

2.1.10.4 Vibration Control. Many factors influence the maximum vibration severity level to which compressor equipment, drivers, and transmission devices may be exposed. The manufacturer should be consulted for values related to specific equipment. Vibration and shaft movement alarms and shutdowns should be used to avoid destructive failures.

Constant monitoring is generally not provided if the application is not critical or the loss of the machine has a relatively low economic impact. In such cases the vibration levels should be determined periodically utilizing hand held vibration measuring equipment, as part of a preventive maintenance program. Again, the maximum allowable overall vibration level should be based upon the manufacturers' recommendations and/or the user's experience.

2.1.11 Parallel Operation

2.1.11.1 Reverse Flow. Air compressor systems employing compressors operating in parallel shall include individual discharge check valves.

2.1.11.2 Isolating Valves. Air compressor systems with compressors operating in parallel shall be provided with individual compressor discharge block (or isolating) valves. These valves shall be so designed and installed as to permit maintenance to be performed in a safe manner. Check valves and flow or pressure control valves shall not be used as block (or isolating) valves.

Selection of the valve operating rate shall consider the potential hazards of pressure shock or explosion due to rapid closure. The preferred arrangement for block valving is a positive closing valve with a vent valve located between it and the compressor, as shown in Fig. 1.

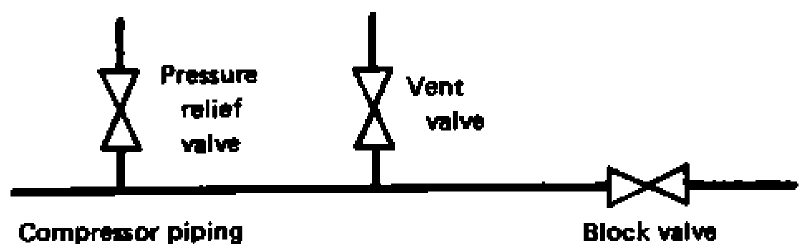

Figure 1, Block Valving

An acceptable alternate arrangement is the use of a three-way valve operating as a combined block and vent valve, as shown in Fig. 2. If a three-way valve is used, it shall be provided with stops to prevent venting the piping while keeping pressure on the compressor.

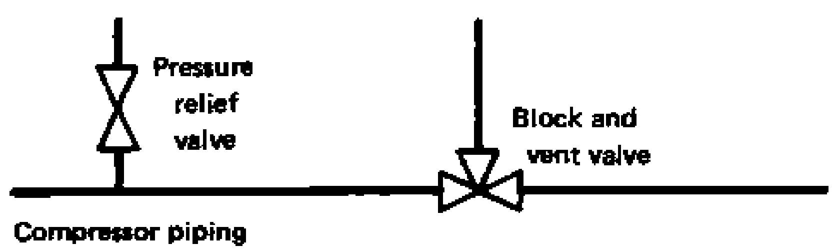

Figure 2, Combined Block and Vent Valve

Isolating valves, to best serve maintenance procedures, should be located just prior to the junction of the individual compressed air piping (lateral) into the first common piping (header).

2.1.12 Noise.
Protection against the effects of noise exposure shall be provided in accordance with OSHA Section 1910.95. Compressor manufacturers should be consulted regarding expected noise levels. Other system components such as valves, inlet piping, and separators can generate noise, and the manufacturers of these components should be consulted also. Manufacturers are able to offer system components that have been specifically designed or treated to reduce their noise levels. Should a system not meet OSHA requirements, the affected area shall be clearly identified and warning signs posted at all entrances.

2.1.13 Remotely Controlled Air Compressor Systems

2.1.13.1 Warning Sign. Remotely controlled air compressor systems shall prominently display a sign on the compressor exterior reading as follows, or the equivalent, including ISO Symbols:

WARNING
This compressor is remotely controlled and may start or stop at any time.

A sign should also be installed on the building access door or enclosure gate. When practical, the sign should conform to the requirements of ANSI Z535.2.

Air compressor systems operating on automatic start-stop, dual control, or automatic dual control are considered here to be remotely controlled.

2.1.13.2 Local Shutdown. Remotely controlled air compressor systems shall include a local shutdown near the compressor. The local shutdown system shall include provisions to prevent remote starting of the compressor. Such shutdown shall be clearly marked.

2.1.14 Nameplate and Rotation Arrows.
Each major component of the air compressor system shall have a permanently attached and clearly visible nameplate made from corrosion resisting material and carrying, as a minimum, the information listed below by component type.

Rotation arrows shall be cast in or permanently attached to each major item of rotating equipment

2.1.14.1 Compressor. The nameplate on the compressor shall show the following:
(a) Manufacturer
(b) model designation
(c) serial number (if applicable)
(d) maximum allowable working pressure

The following additional information should be considered for inclusion on the nameplates:
(a) instruction manual number
(b) maximum allowable cooling water pressure and temperature
(c) maximum allowable discharge temperature
(d) capacity

(e) rated inlet pressure
(f) rated discharge pressure
(g) rated operating speed
(h) rated input power
(i) hydrostatic test pressure
(j) maximum allowable operating speed

2.1.14.2 Electric Motors. Constant speed electric motors shall include nameplates as specified in the NEMA MG-1 standard. In addition, motors for use in hazardous locations shall show ambient classes for which they are suitable.

2.1.14.3 Other Drivers

(a) Internal Combustion Engines. The nameplate shall show:
(1) manufacturer
(2) model designation
(3) serial number
(4) maximum allowable operating speed

(b) Steam Engines. Steam Turbines and Energy Recovery Expanders. The nameplate shall show:
(1) manufacturer
(2) model designation
(3) serial number
(4) rated inlet pressure
(5) rated inlet temperature
(6) rated discharge pressure
(7) rated power output
(8) maximum allowable operating speed

(c)-Combustion Gas Turbines. The nameplate shall show:
(1) manufacturer
(2) model designation
(3) serial number
(4) rated power output and basis for rating
(5) maximum allowable operating speed
(6) maximum allowable operating temperature
(7) fuel type
(8) fuel pressure limits
(9) water or steam injection pressure limits (if applicable)

2.1.14.4 Other Components

(a) Electric Motor Controls. Electric motor control devices shall include a nameplate to NEMA standards. The following information should be considered for inclusion on the starter panel nameplate:
(1) enclosure type

(2) line voltage
(3) number of phases
(4) control voltage if other than line voltage

(b) Heat Exchangers. Nameplates on heat exchangers that are remote components of an air compressor system shall show:
(1) manufacturer
(2) model designation
(3) serial number
(4) pressure rating (both sides if shell and tube)
(5) temperature rating (both sides if shell and tube)
(6) ASME pressure vessel information (if applicable)

(c) Pressure Vessel and Relief Valves. Nameplates on pressure vessels and relief valves shall conform to the requirements of Section VIII, Division 1 of the ASME Boiler and Pressure Vessel Code.

(d) Miscellaneous Components of Air Compressor Systems. Components not covered above and which are not pipe, fasteners, conduit wire, or similar hardware shall be marked to identify:
(1) manufacturer
(2) model designation
(3) maximum pressure (if applicable)
(4) operating voltage (if applicable)
(5) direction of flow (if applicable)

Components would include items such as air dryers and line filters. The function of these devices should be described in the operator's manual.

2.1.15 Foundations.
Foundations for compressors shall be designed and constructed to minimize machine vibration, foundation movement, and transmission of vibration to surrounding structures. Where compressors are designed to be fixed to the foundation, movement shall not be permitted between the compressor and the foundation. Where compressors are designed for flexible mounts (vibration isolators) all piping and electrical connections shall be designed with adequate flexibility to withstand movement.

In the case of compressors which are grouted in, the following points are suggested:
(a) wedges, plates, jackscrews, and shims should be removed after grouting;
(b) the compressor should be attached to its foundation in accordance with the manufacturers recommendations
(c) the compressor should not be operated until the grouting material has thoroughly hardened.

The premises surrounding a new compressor installation should be carefully inspected by the owner to locate and correct resonant vibrations which may occur in building walls, piping, stacks, and other structures as a result of the compressor operation.

2.1.16 Lifting Provisions.
Components or assemblies weighing more than 100 lb (45 kg) which can be damaged by incorrect rigging procedures shall be provided with obvious lifting eyes, lugs, lifting provisions, or eyebolts, or shall be accompanied by lifting instructions.

Components of air compressor systems should not be shipped or moved in larger sections than can be safely handled. Damage due to incorrect handling can include misalignment, distortion, line breakage, or crimping. Such damage, if undetected, can present a serious safety hazard.

2.1.17 Electric Motors.
Electric motors, their controls, and wiring shall be designed and installed in accordance with NFPA 70 and NEMA MG1, MG2, ICSl, and ICS2. Motors should be maintained in accordance with the manufacturer's instructions and NFPA 70B. Should a conflict exist, the manufacturer's instructions should be given preference. Safety requirements shall be in accordance with NFPA 70E.

2.1.18 Air Receiver Tanks and Other Pressure Containing Compressor Auxiliaries.
Air receiver tanks and other pressure containing auxiliaries (air dryers, heat exchangers, filters. aftercoolers, and pulsation suppression devices) shall be designed in accordance with the ASME Boiler and Pressure Vessel Code, Section VIII, Division 1.

Piping shall be designed, manufactured, installed, and tested per ASME B31.3 as outlined in 2.1.1.

Air receiver tanks and other pressure containing auxiliaries shall be maintained and retested on a regular basis to comply with the regulations of the jurisdiction in which the vessels are located and OSHA Section 1910.169. Manufacturer's instructions should list a schedule of recommended maintenance and testing procedures.

2.1.19 Air Reheaters.
Direct fired reheaters shall not be used. Compressed air shall not be reheated to a temperature higher than the maximum allowable compressor discharge temperature if oil carryover or other fire-causing contaminants are possible. If reheating is necessary, oil free compressors are recommended, as well as filtered inlet air. Reheating can be minimized by controlling moisture intake.

2.2 Operation and Maintenance

2.2.1 General.
Before placing the equipment in operation (initially and each succeeding startup), the operating chief and/or supervisor shall ensure that the manufacturer's recommendations and all appropriate safety codes (ANSI/AMT Bl5.1, for example) have been met regarding safety and protection of personnel in the equipment vicinity. This includes items such as installed guards, closed electrical enclosures, insulation of hot pipes, and visible, readable warning signs.

Good maintenance and repair procedures can contribute to the safety of the maintenance crew as well as operating personnel. Therefore, supervisors should establish comprehensive maintenance and operating procedures with periodic reviews with affected personnel and instruction for new hires. These procedures should cover startup, break-in period, routine operation, routine maintenance, preventive maintenance, troubleshooting, and overhaul, with the manufacturer's instructions as a basis.

Competent observation of compressor performance is one of the best methods of determining need for maintenance which, in turn, can be the best safety precaution available. Any damage observed or suspected should be reported to supervisors. If the condition impairs safe operation, the machine shall be taken out of service for repair in the prescribed safe manner. Safeguards that have been altered or damaged should be reported so appropriate action can be taken to ensure against worker injury.

Records showing the history of operation, maintenance, inspections, and testing should be kept and reviewed regularly. These records should be a part of normal operation and maintenance. Such records form an important diagnostic tool. This tool can result in a safe working place, optimum operation, minimum maintenance expense, and aid predictive maintenance. The air compressor system supplier is normally able to assist the owner and supervisors in establishing the type of records to be kept.

2.2.2 Lockout Procedure.
Lockout procedures shall be in accordance with NFPA 70E. Since maintenance or repair workers could be exposed to electrical elements and hazardous moving machine parts in the performance of their jobs, the power sources and control power shall be shut off and locked out before the work begins. Warning signs or tags are inadequate protection against the untimely energizing of the mechanical equipment. Suitable starting prevention systems could be the following:

- *(a)* pulling fuses and locking the fuse box cover;
- *(b)* locking the power switch in the open position with a lockout clasp for both the power source and the control power;
- *(d)* removing ignition components from spark ignited engines and combustion gas turbines;
- *(e)* blanking off the steam supply or gas supply to steam turbines and expanders, respectively;
- *(f)* closing double block valves and venting between them for fluid powered drivers;
- *(g)* disconnecting the coupling between the driver and the compressor is also recommended in addition to de-energizing the driver.

Tagging, in addition to lockout, is recommended to clearly establish the repairs being made and alert remote operators so that safe operation of the entire plant can be achieved.
Note: When in doubt, overprotect.

Responsibility for restart shall be in the hands of the person performing the maintenance. Positive prevention against rollover should be achieved by crankshaft blocking and rotor blocking.

2.2.3 General Operating Procedures.
Pressure relief valves, shutdown and alarm devices, and air inlet filters shall be checked on a regular basis (refer to the manufacturer's instructions for suggested frequency and procedures). The frequency of cleaning and testing should be annual unless the manufacturer recommends shorter intervals or the operating history indicates shorter intervals are necessary to provide safe operation.

Pressure relief valves should be removed on a regular basis for cleaning and testing with pressure so that the seats will be blown clear of foreign matter.

Filters cease to function properly when they are plugged with dirt or have openings or bypass areas that allow foreign matter to enter the compressor. The manufacturer's recommendations concerning maximum filter pressure drop and normal cleaning period should be followed. Dirt in an air compressor system causes abnormal wear, inefficient compression, air contamination, inefficient heat transfer surfaces, and, in some cases, fires.

Oil wetted or oil bath type air inlet filters shall use oils that have a flash point greater than the flash point of the compressor lubricant. Filters and filter elements shall not be cleaned with combustible solvents.

The overspeed shutdown device shall be tested regularly and should be tested at least on an annual basis. Three consecutive tests of the device should be conducted to ensure repeatability of the overspeed setting.

Any safety device required by this Standard shall not be jumpered, bypassed, or defeated by any person. In the event that shutdown of the air system would impose a more hazardous condition, the owner shall install a backup air system drive train to maintain safe operation of the overall plant.

2.2.4 General Maintenance Procedures.
Before maintenance procedures involving the disassembly of the system are begun, the system shall be relieved to atmospheric pressure and locked out per 2.2.2. Venting shall be through a lockout system, such as a locked open valve, and/or removal of a closure (blind or plugged connection). Prior to removing the blind or plugged connection, be sure all pressure has been relieved. Tag the opening and the control panel so that startup does not occur prior to replacement.

Volatile, flammable, or cleaning fluids injurious to health of personnel shall not be used to clean parts. After cleaning, all parts shall be rinsed and dried. Consult the Federal Register, OSHA Section 1910, for specific details regarding ventilation and exposure limits.

(a) Crankcase and Heat Transfer Surface. If a compressor crankcase is to be opened for any reason, a minimum of 15 min shall elapse between shutdown and exposure of the crankcase to the atmosphere. A warning plate shall be provided by the manufacturer and also noted in the owner's maintenance procedures if opening the crankcase would present a hazardous condition.

Heat transfer auxiliaries shall be inspected and cleaned regularly to prevent fouling that could cause a fire or a system overpressurization due to sludge buildup.

(b) Startup Procedures. On initial startup and any startup after disassembly of compressor or system internals, the following items shall be performed:

(1) Check all valves for proper positioning.
(2) Remove all blinds installed for maintenance safety.
(3) Check and remove from the system all foreign objects.
(4) Follow the established lockout device(s) procedure for removal.
(5) Replace all safety guards.
(6) Replace all warning/safety signs.
(7) Open and reclose all drains.
(8) Notify all personnel in the area that startup is about to occur. (NOTE: Also notify remote operators.)
(9) Manually rotate the equipment to ensure that no mechanical interference exists. (NOTE: Reciprocating compressor unloaders shall be in the full load position.)
(10) Ensure that driver rotation is correct.
(11) Check and verify proper operation of all safety devices, especially overspeed trip, and pressure relief devices.
(12) Observe that normal combustion has occurred on engines or gas turbines; if not, shut down immediately and take corrective action. Consult the manufacturer's instruction.

2.2.5 Fires and Explosions.
Fires or explosions involving air compressors can be classified into two general categories: those in which compressor lubricating oil is in contact with airstream and those involving closed-loop operation.

(a) Lubricating Oil in Contact With Airstream. The majority of fires or explosions in air compressor systems have involved reciprocating machines. The fuel for air compressor fires is the cylinder lubricating oil itself or the carbonaceous products formed by oxidation of the lubricating oil. The formation of carbonaceous deposits in air compressor systems depends on the amount and type of the lubricating oil used and the temperature of the metal surface on which the oil is deposited. These effects appear to be interrelated. An operating temperature which is satisfactory with the correct amount of oil may cause carbon deposition if excess oil is used. The mechanism by which the fuel in air compressor fires is ignited is not definitely known; however, a factor common to all theories of ignition is excessive temperature, which may involve either the gas itself or a localized condition resulting from mechanical friction. High temperature is also important because it promotes deposition of carbon in the compressor system. Excessive temperatures are generally caused by valve or cooling water failures or by operation at unusually high compression ratios. High operating speeds combined with ineffective jacket design also promote high cylinder temperatures. To minimize the risk of fires and explosions in positive displacement air compressors, the following precautions are recommended:

(1) Use nonlubricated compressors.
(2) Provide high temperature alarms and cutouts in compressor discharge.

(3) Use the minimum amount of lubricating oil that will lubricate the cylinder satisfactorily and train operators to detect significant increases in lubricating oil consumption. Use the least viscous oil that will satisfy operating conditions.
(4) Train operators to detect faulty compression cylinder valves and have repairs made promptly.
(5) Take inlet air from a cool, clean location. Provide air filters (preferably of a dry type) and service at regular intervals.
(6) Provide intercoolers to maintain interstage suction temperatures at lowest practicable level. Keep intercoolers and cylinder jackets free of deposits.
(7) Inspect reservoirs, cylinder, pulsation dampener, discharge pipe, afterfilters, etc., regularly. Remove deposits and oil accumulations. Provide access for inspection and cleaning.

(b) Closed-Loop Compressor Operation. Leakage of lubricating oil from seals or bearings into a closed loop can create a flammable mixture, and if coincident with such a condition an element in the machine becomes overheated, a serious explosion may result. To prevent disasters of this type, bearings and oil seals of centrifugal or axial compressors for closed loop air systems should be designed to prevent lubricant carry-over into the compressor. If there is any possibility of oil carrying into the compressor, closed loop air systems shall not be used.

2.3 Synthetic and Fire Resistant Lubricants.
Synthetic or fire resistant lubricants shall not be substituted for the originally supplied lubricants in compressed air systems without written agreement from the air compressor manufacturer. Items of concern are toxicity, carryover effects, compatibility with seals (gaskets and o-rings) and hoses, compatibility with other components in the air system, plugging of air lines, and lubrication effects.

Section 3 - Requirements and Conditions Applying to Air Compressor Systems by Cooling Type

3.1 Air Cooled Systems

3.1.1 Ventilation.
Essentially, most of the energy supplied to the compressor is dissipated to the air in the form of heat. Unless this heat is removed, it can raise the air temperature of the compressor's surroundings to a dangerous level.

Sufficient ventilation shall be provided in air cooled installations to comply with the manufacturer's ambient temperature limits.

3.1.2 Cooler Fouling.
The air cooled air compressor system shall be so maintained that intercooler and aftercooler effectiveness is not seriously impaired. The effectiveness should not be allowed to fall below 65% of the effectiveness when new under the controlled conditions of flow, power and humidity. Effectiveness as percentage of new effectiveness is here deemed as the ratio of the air temperature drop in the cooler in the fouled condition to the temperature drop when new.

Fouling can occur on either the tube side or the ambient side. Tube side fouling is usually in the form of lubricating oil residue and normally is the result of improper lubricating oil, dirt passing through the inlet filter, poor maintenance, operation at higher than rated pressures and temperatures, or poor ventilation.

The majority of fires and explosions in air compressor systems involve oil lubricated compressors. The fuel for the fire is cylinder lubricating oil or the carbon products fanned by oxidation of the lubricating oil. Excessive temperatures tend to encourage fires. Every effort should be made to maintain normal operating temperatures.

Fouling on the ambient side is usually in the form of dust, leaves, and other debris. Clean surroundings and elimination of oil leaks will minimize the problem.

Manufacturer's instructions should be consulted for both prevention and cure.

3.1.3 Fans

(a) *Guards.* Fans and their drives shall be guarded (see OSHA Part 1910).
(b) *Blades.* Fans shall be operated at a speed not exceeding manufacturer's rating. Fans with adjustable blades should be provided with devices which positively prevent the blade from leaving the hub during operation.
(c) *Critical Speeds.* Fan systems are relatively low power and high inertia systems that are particularly vulnerable to critical speed and vibration problems. All fan drives shall be capable of the following:
    (1) accelerating to operating speed and decelerating safely with their design driver;
    (2) operating throughout their design speed range safely;
    (3) surviving excursions to and through emergency overspeed shutdown including shutdown deceleration.
(d) *Balance.* If a fan becomes unbalanced, the condition shall be corrected immediately. Balance shall be in accordance with ISO 1940, Balance Quality Grade 6.3, or the manufacturer's limit, if more stringent.

Manufacturer should be consulted for vibration limits. Consideration should be given to automatic vibration shutdown devices on large fans.

3.2 Liquid Cooled Systems

3.2.1 Cooler Fouling.
The liquid cooled air compressor system shall be so maintained that intercooler effectiveness and aftercooler effectiveness are not seriously impaired. The effectiveness should not be allowed to fall below 65% of the effectiveness when newwhen new under the controlled conditions of flow, power and humidity. Effectiveness as percentage of new effectiveness is here defined as the ratio of the air temperature drop in the cooler in the fouled condition to the temperature drop when new.

Air side fouling is usually in the form of lubricating oil and its residue and normally is the result of improper lubricating oil, incorrect lubricator settings, poor maintenance, or operation at higher than rated pressure.

The majority of fires and explosions in air compressor systems involve oil lubricated compressors. The fuel for the fire is the cylinder lubricating oil or the carbon products formed by oxidation of the lubricating oil. Excessive temperatures tend to encourage fires. Every effort should be made to maintain normal operating temperatures.

Fouling on the water side is almost always in the form of scale and water derived sludge. While there may be no cure for all sludge and scale formation, certain combinations of water flow rate and temperature control are often used to minimize the problem. In closed water systems using cooling towers, attention should be given to pH, dissolved solids, blowdown rate, and circulation rate to minimize scale and sludge formation.

Water jackets, tubular or radiator-type exchangers, piping, and liquid holding tanks shall be provided with drainage facilities to prevent freezing during idle periods.

3.2.2 Radiator Cooled Systems

3.2.2.1 Thermal Expansion. Where an air compressor system employs a radiator-type heat exchanger for heat dissipation, the system shall include provision for thermal expansion of the working fluid. Usually a surge tank is mounted directly above the radiator to provide for expansion. Alternatively, the system shall be provided with a pressure relief device.

3.2.2.2. Fans

(a) *Guards.* Fans and their drives shall be guarded. See OSHA Part 1910 and ASME B15.1 for more details.
(b) *Blades.* Fans shall be operated at a speed not exceeding manufacturer's rating. Fans with adjustable blades should be provided with devices which positively prevent the blade from leaving the hub during operation.
(c) *Critical Speeds.* Fan systems are relatively low powered and high inertia systems and are particularly vulnerable to critical speed and vibration problems. All fan drives shall be capable of the following:
    (1) accelerating to operating speed and decelerating safely with their design driver;
    (2) operating throughout their design speed range safely;

(3) surviving excursions to and through emergency overspeed shutdown including deceleration.

(d) *Balance.* If a fan becomes unbalanced, the condition shall be corrected immediately. Balance shall be in accordance with ISO 1940, Balance Quality Grade 6.3 or the manufacturer's limit, if more stringent.

Manufacturer should be consulted for vibration limits. Consideration should be given to automatic vibration shutdown devices on large fans.

3.2.3 Pressure.
Water outlet throttling devices shall not be used where the water supply pressure is higher than the maximum working pressure of any water cooled portion of the air compressor system.

An inlet pressure control device shall be used to control the water pressure, and a suitable pressure relief device shall be installed downstream of the pressure control valve.

Block or isolation valves shall not be installed between the pressure control valve and the pressure relief valve.

The piping arrangement shall be such as to preclude siphon action.

3.2.4 Leaks.
Before initial startup and after maintenance involving the cooling system(s), the following procedures shall be followed:
(a) check the system for leaks, particularly for leaks into compression and lubricating oil sections;
(b) check the cooling system to be sure the water flow is adequate.

3.2.5 Strainers.
To reduce cooler system fouling and blockage, suitable filters should be used to remove solid materials.

3.2.6 Pressure Relief Devices.
Water cooling systems which can be closed off by valving or other means shall be fitted with devices that provide for thermal expansion of the fluid, or, alternatively, shall be provided with a pressure relief device.

Section 4 - Requirements and Conditions Applying to Special Air Compressor Systems

4.1 Hand Portable Systems

Hand portable systems are defined as air compressor systems of such size, weight, and design that they can be transported by one or two persons by manual lifting or by moving wheelbarrow style.

4.1.1 General.
Hand portable mountings shall be specifically designed to protect an untrained and unsuspecting operator.

4.1.2 Air Receivers.
All air receivers shall be designed in accordance with Section VIII, Division 1 of the ASME Boiler and Pressure Vessel Code regardless of size. All weldments and other attachments to air receivers shall meet that Code's requirements. Air receivers shall be provided with facilities to permit bottom drainage.

4.1.3 Electric System.
The electric system shall be in accordance with NFPA 70.

4.1.4 Electric Motors.
Electric motors shall be protected against overload.

4.1.5 Instructions.
Operating instructions or reference to the proper operating manual shall be clearly printed on a visible surface of the air compressor system.

4.2 Mobile Compressors

Mobile compressors are defined as self-contained air compressor systems mounted on a wheeled and readily mobile chassis. The air receivers on such systems shall be depressurized prior to being transported.

4.2.1 Oversteering.
Four wheeled mountings shall include an oversteer safety mechanism or turn limiting device to prevent damage to the running gear in the event that the towing vehicle has a shorter turning radius than the mobile compressor.

4.2.2 Towing System.
The towing system back to and including the chassis and running gear shall have all stressed members made of ductile material.

4.2.3 Safety Chains.
Mobile compressors shall be provided with a safety chain towing system.

4.2.4 Reflectors.
Mobile compressors shall be provided with two reflectors on the rear and at least one on each side.

4.2.5 Starting.
General operating instructions shall be attached to the compressor. Wheels shall be chocked to prevent rolling before starting the unit

4.2.6 Towing Speed.
Mobile compressors arc not normally designed for over-the-road use; however, mobile compressors that have chassis and signal equipment specifically designed for over-the-road use shall be provided with a conspicuously located sign which displays the maximum safe towing speed.

4.2.7 Air Receivers.
All air receivers shall be designed in accordance with Section VIII, Division 1 of the ASME Boiler and Pressure Vessel Code. All weldments and other attachments to air receivers shall meet that code's requirements. Air receivers shall be provided with facilities to permit bottom drainage.

4.3 Nonlubricated Reciprocating Compressors

4.3.1 Instruction Manual.
Instruction manuals for nonlubricatcd reciprocating compressors shall clearly explain all special maintenance procedures. Particular attention shall be given to avoiding metal-to-metal sliding contact.

4.3.2 Inlet Piping.
Inlet lines to nonlubricatcd reciprocating compressors shall have noncorroding inner surfaces downstream of the inlet filter.

4.4 High Pressure

4.4.1 General.
Those portions of an air compressor system operating at pressures in excess of 175 psig (12.1 bar gage) will be referred to as high pressure.

Consideration should be given to the use of high temperature and oxidation resistant lubricants.

With increasing air pressure, the following effects are found:
(a) oxygen partial pressure increases (more oxygen per unit of compressor volume);
(b) oxidation reactions, including combustion, take place at higher rates of speed and at lower temperatures;
(c) stored energy density increases, with attendant increase in destructive capacity, if mishandled.

4.4.2 Piping.
High pressure piping should be carefully designed with attention given to the avoidance of accumulation of coke and other deposits on inner surfaces and temperature effects.

Added attention should be given to pipe inspection to avoid sludge buildup.

4.4.3 Overtemperature Protection.
Additional requirements shall be as follows:
(a) high discharge temperature shutdowns shall be installed before each cooler;
(b) shutdown setting shall not exceed 50°F (28°C) above normal operating temperature. (This is a maximum setting and should be reduced where practical.)

4.4.4 Lubricants.
Consideration should be given to the use of high temperature and oxidation resistant lubricants, such as synthetics. When special lubricants are required, the type shall be clearly marked near the lubricant fill nozzle.

4.5 Vacuum Pumps
Systems incorporating vacuum pumps shall be designed in accordance with the mandatory practices given elsewhere in this Standard

4.6 Systems Providing Air for Human Respiration
ANSI/CGA G-7.1 or equivalent, shall apply.

4.7 Engine Starting Systems
(a) *Causes of Explosions.* Numerous fires and explosions which have occurred in starting air systems while starting large internal combustion engines have been traced to accumulations of lubricating oil in the starting air line, coincident with faulty air check valves. When these conditions exist concurrently, the following sequence of events is possible:
  (1) Leakage of fuel gas through a check valve that is stuck or leaking creates a flammable mixture in the starting air line.
  (2) The mixture can be ignited from the power cylinder.
  (3) Flame propagates through the air check valve and starting air line.
  (4) Depending on pressure, temperature, and quantity of lubrication oil or gas in the starting air line, a fire or explosion may follow. Detonations in starting air lines are particularly destructive because they travel at a very high speed, and they produce very high localized pressures due to shock waves. For these reasons, relief valves or rupture disks have not prevented rupture of starting air lines when conditions were favorable to detonation.
(b) *Prevention of Explosion.* To minimize the risk of explosions in starting air systems, the following precautions are recommended:
  (1) Thermometers, thermocouples, or other temperature sensing devices installed in discharge piping should be monitored to detect fouled or defective valves.
  (2) Any increase in compressor oil consumption should be investigated.
  (3) Intake air filters should be kept clean.

(4) Discharge temperature of any stage of a starting air compressor shall not exceed 350°F (177°C) for lubricated compressors.
(5) Starting air header on engine should be vented during normal operation.
(6) Receivers and low spots in air piping should be blown down on a regular schedule. Low spots in piping should be fitted with drains.
(7) Air receiver and interconnected piping should be inspected on a regular schedule. Oil or dirt accumulation should be removed.
(8) Starting air check valves and air pilot valves on engines should be included as part of regularly scheduled maintenance.
(9) Use nonlubricated compressors.

(c) Automatic compressor shutoff for high temperature shall be provided. Visible and audible alarms for high discharge temperature of each stage in the starting air compressor is also recommended.

4.8 Underground Systems

The standards of the United States Bureau of Mines shall apply.