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Revision Memo

04/04 Design and Global Practices **numbering and title** updated.
Page 3: **Differential pressures** updated.
Page 5: GP10-3-3 **Testing** requirements updated.
Page 7: Compressors **pressure and capacity** availability added.



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SCOPE

This section presents aspects of rotary compressors pertaining to compression service design and compressor type selection, with special emphasis on high-pressure oil free helical screw compressors. Background material is included to acquaint the compression service designer with factors which affect equipment selection and installation design.⁽¹⁾

REFERENCES

DESIGN PRACTICES

Other subsections of DP XI

[DP V](#) Drums

[DP XV](#) Safety In Plant Design

[DP XVIII](#) Air Pollution Control, Industrial Hygiene and Noise Control

GLOBAL PRACTICES

GP 3-9-1, Winterizing and Protection Against Ambient Temperatures

GP 10-3-3, Rotary Screw Compressors

GP 15-1-2, Instrumentation for Compressors and Drivers

OTHER REFERENCES

API-619, *Rotary Type Positive Displacement Compressors for Petroleum, Chemical, and Gas Industry Services*.

Compressed Air and Gas Handbook, Compressed Air and Gas Institute.

BACKGROUND

GENERAL

The term rotary describes a class of compressors which operate on the positive displacement principle and employ a predominately rotary motion. A number of different types and construction styles have been developed within this class of compressor and they employ different mechanical principles and configurations. The various types are applied to petroleum and chemical plant services, but in smaller numbers than are reciprocating and centrifugal compressors. They are limited to relatively low discharge pressures and low power levels. Some types have distinctly lower maintenance requirements than reciprocating compressors. The high-pressure oil free helical screw compressor has been successfully applied in a wide variety of air and gas services over the past 30 years and is an important economic competitor in the flow and pressure range for which it was developed.

The high-pressure oil free rotary compressor is by far the most significant rotary compressor type applied in major process gas and utility air services. **GP 10-3-3, Rotary Screw Compressors**, covers the technical requirements for this type of compressor. **GP 10-3-3** also contains the requirements of **API-619**. These standards are primarily intended for rotary compressors that are in continuous duty and are generally unspared. The following discussions pertain to oil free high-pressure helical screw type compressors. For a discussion of other rotary compressor types, see **APPENDIX A, OTHER ROTARY COMPRESSOR TYPES**.

SERVICEABILITY AND SPARING

See [DP XI-C, Compression Machinery Serviceability and Sparing](#), for reliability factor information and recommended sparing practices.

Note:

(1) API compressor data sheets specify pressure in psi, bar, and kPa. In this section, bar is the metric unit used for pressure.

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BACKGROUND (Cont)

OPERATING PRINCIPLES

The helical screw compressor is a positive displacement type compressor. [Figure 1](#) shows a typical high-pressure helical screw compressor with its upper casing removed. Compression is achieved by the intermeshing of two helically formed rotors: a male rotor with convex lobes and a female rotor with concave flutes. Gas is admitted through an inlet port and fills the helically shaped flutes along the length of the female rotor. The discharge end of the rotor cavity is confined by the compressor endplate. As the rotors turn, a lobe of the male rotor progressively enters the flute cavity in the female rotor, decreasing the cavity volume and raising the pressure of the trapped gas. The compressor is designed so that a built in compression ratio is attained at the point in the rotation cycle where the discharge port in the discharge end plate is uncovered. The process is repeated for each interlobular space. For a given size of compressor, designs are available with a range of built in compression ratios. The built in compression ratio is selected by the vendor to optimize compression efficiency on a service by service basis. See [Figure 2](#).

BASIC CONSTRUCTION

The male and female rotors operate dry in the process gas without the presence of oil as a lubricant. In order to prevent rotor contact and wear, in the absence of lubricant, the male and female rotors are prevented from contacting by timing gears. See [Figure 1](#). The compressor inlet gas volume handling capability and compression ratio are determined by rotor length, helix angle of the lobes, and the location and shape of the discharge port. Normally there are four lobes on the male rotor and six flutes on the female rotor. Consequently the male rotor rotates 50% faster than the female rotor. Each rotor is supported by two pressure lubricated hydrodynamic type radial bearings, and a hydrodynamic thrust bearing is provided for each rotor. Anti friction bearings are used on light duty designs. Four shaft seals, two per rotor, are required to prevent compressed gas leakage to atmosphere.

BASIC DESIGN CONSIDERATIONS

COMPRESSOR STAGING - The choice of the number of compressor stages is determined by discharge temperature and differential pressure limitations.

Allowable Discharge Temperature - Where there is no limit to discharge gas temperature due to gas considerations such as polymerization, the discharge temperature of a compressor stage should be limited to 350°F (175°C). A higher discharge temperature to approximately 450°F (230°C) is achievable by using an oil cooled rotor design. The oil is circulated through the rotors for cooling not injected into the gas stream.

For guidance in determining helical screw compressor discharge temperatures, see [DP XI-D, Compression Calculations](#). The recommended discharge temperature limits should be observed in determining the number of helical screw compressor stages used in a given compression service.

- ◆ **Pressure Differential** - Pressure differential, discharge pressure minus inlet pressure, is limited since pressure difference causes rotor bending which can result in casing contact. A differential pressure of 10 to 150 psi (0.7 to 10.0 bar) is readily achievable. 10 to 200 psi (0.7 to 14.0 bar) is probably achievable by most vendors using rotors with low length to diameter ratios.
- ◆ **Guidelines on Staging Selection** - To ensure the proper staging arrangements, it is recommended that vendor and machinery specialist assistance be obtained in selecting compressors with the following service conditions:
 1. Pressure difference across stage in excess of 150 psi (10.0 bar). It is expected that a pressure difference up to 200 psi (14 bar) will be achievable but should be confirmed.
 2. Discharge temperature above 350°F (177°C). Higher temperatures to 450°F (230°C) should be achievable but should be confirmed.
 3. Compressor capacity in excess of 40,000 acfm (67,000 m³/hr). In large capacities, rotor differential pressure limits must be confirmed as large compressors may have differential pressure limits below 150 psi (10.0 bar). See [DP XI-B, Compressor Type Selection](#), for additional information on compressor flow and discharge pressure application range data.

SHAFT SEALS

Main Shaft Seal Types - The compressor main shaft seals are located at both ends of each rotor. In the dry or oil free helical screw compressor, there are four seals, two per rotor. Three types of seals are commonly used. These are the labyrinth, restrictive ring, and mechanical (contact) type oil seal. For a description of these seal types, see [DP XI-E, Centrifugal Compressors, Shaft Seals](#). Self acting gas seals also described in [DP XI-E](#) have limited experience and are not considered to be an economic choice for the low operating pressure levels experienced in screw compressor services. Gas seals should be applied only after consultation with the vendor and machinery specialists.

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BASIC DESIGN CONSIDERATIONS (Cont)

- ▶ **Shaft Seal Type Selection** - **API-619** requires that the purchaser specify the type of shaft seal to be used. The following recommendations assume that specialists in the areas of industrial hygiene, air quality, and safety will review the service and provide the inputs necessary to determine the adequacy of the proposed arrangements. See [DP XVIII-B](#), *Guidelines for Industrial Hygiene*.
 - **Labyrinth and Restrictive Ring Seals** - Labyrinths are recommended for all air services. Labyrinth and restrictive ring seals may be used only for nitrogen or other inert gas services. These recommendations assume that the gas stream is **Respiratory Class R-4** and no fugitive emission limits apply. Typically the maximum temperatures and pressures to which these seals should be exposed are 350°F (175°C) and 150 psig (10 barg). For other applications machinery specialists should be consulted.
 - **Mechanical (Contact) Oil Seals** - This seal type uses oil injection to minimize leakage of process gas to atmosphere and is suitable for sealing gas streams with **Respiratory Classes R-1 through R-4**. This type of seal is considered suitable for the pressures encountered in screw compressor service. It is applied in services up to 650 psig (45 bar) and 350°F (175°C) in centrifugal compressor applications. For other applications machinery specialists should be consulted.

LUBE OIL AND SEAL OIL SYSTEMS

See [DP XI-E](#), *Centrifugal Compressors, Lube Oil, Seal Oil, and Gas Seal Systems*. The use of separate lube and seal oil systems is rare in screw compressor applications as they would require additional rotor length and could affect the differential pressure capability of the compressor therefore, should the use of a separate lube and seal oil system appear necessary based on a review of the [DP XI-E](#) reference, a machinery specialist should be consulted.

CONTROLS AND INSTRUMENTATION

General - The Design Specification should provide a description of the compressor process control scheme. It should identify the controlled variable, the source of the control signal, and the control method, e.g., bypass control, speed control, etc. Fail safe modes for control elements should be shown.

Capacity Control Methods - The Design Specification must identify the method by which the compressor flow capacity will be regulated to maintain control of the chosen process variable. Methods of controlling the compressor net capacity are as follows:

- **Bypass Control** - An external bypass around the compressor is provided to recycle gas from the compressor discharge to the inlet or to the atmosphere in the case of an air compressor. Care must be taken to ensure that the bypassed gas is cooled before returning to the compressor inlet to avoid excessive stage discharge temperatures.

For operating flexibility, it is recommended that the recycle line, control valve, and cooling capacity be selected to handle the entire capacity of the compression service. It is also recommended that the recycle line return gas to the compressor upstream of the inlet knockout drum to remove any liquids and facilitate pipe cleaning during commissioning.

Bypass control is preferred in constant driver speed applications because of its smoothness, simplicity, and low investment cost. It is, however, inefficient because excess compressor capacity is expanded across the control valve in the recycle line.

- **Variable Speed Drive** - Speed variation is normally achieved by using steam turbines, gas turbines, and variable speed electric motors as drivers. These drivers typically provide a speed range capability of 70 to 105% of normal speed. The lower speed is usually limited by the presence of critical speeds in one or another of the train components. In the absence of critical speed limitations, a reasonable lower speed limit is 50% of normal. Here the limiting factor is internal recirculation of the flow within the compressor. As speed decreases, the ratio of internal recirculated flow (slip) to net flow increases thus increasing the compressor operating temperature. The actual minimum speed limitation must be determined based on an actual machine selection.

Speed control is normally augmented by bypass control to provide wide flow variation and flexibility for machine startup.

- **Slide Valves** - The action of a slide valve is to release the gas drawn into the compressor and trapped between the rotor and casing and return it to the inlet before the compression process starts. No work is done on the released gas which is recycled to the compressor inlet. The slide valve in effect reduces the rotor length and therefore rotor delivery capacity over a range. The capacity control range for the slide valve is approximately 50 to 100% of normal capacity. The slide valve is a machine internal mechanism susceptible to damage by dirt, debris, etc. It is normally applied in clean services such as air and refrigeration services. The specification of slide valve control should be done in consultation with a machinery specialist.

- ▶ **Pressure Relief Valves** - Pressure relief valves are required at the discharge of each rotary screw compressor stage to avoid machine damage due to over pressure. The relief valve setting should not exceed the maximum allowable working pressure of the casing. See [DP XI-A](#), *Compression Service Design Procedures, Casings and Cylinders*. Also see [DP XV-C](#), *Pressure Relief*.