

GAS EXPANDERS**JGS 210-120-1-32E**

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CONTENTS

	<u>PAGE</u>
1. SCOPE	2
2. WORK PROCEDURE	2
2.1 Format	2
2.2 Thermodynamics in Gas Expander Process	2
2.3 Classifications and Applications	2
2.3.1 Process Application	2
2.3.2 Type of Gas Expanders	3
2.3.3 Gas Expander Manufactures	3
3. DESIGN	4
3.1 Details of Gas Expanders	4
3.1.1 Gas Expander Control	4
3.1.2 Safety and Protection Devices	4
3.1.3 Shaft Seals	4
3.1.4 Bearing and Lube Oil System	5
3.1.5 Expansion of Stream Running in Mixed Phase at Discharge	6
3.1.6 Expansion Ratio (for Radial Flow Expander)	6
3.1.7 Length of Discharge Line Straight Portion	6
3.2 Determination of Suction Conditions	7
3.3 Expander Process Calculation Procedure	7
3.3.1 Precaution to be Taken in Calculation	7
3.3.2 Computer Programs	7
3.3.3 Estimation of Efficiency	7
3.3.4 Hand - calculation Method	9
3.4 Required Information and Entries in Data Sheets	10
3. ABBREVIATION	17
APPENDIX A EXPANDER COMPRESSOR DATA SHEET	18

1. SCOPE

This standard practice provide the guidelines (including precautions) required for process engineers to prepare heat and material balances, P&I diagrams and expander data sheets for a gas expander process.

2. WORK PROCEDURE

The data preparation on gas expanders should be executed as follows.

2.1 Format

1 latest JGC standard form data sheet shall be used for the gas expanders.

2.2 Thermodynamics in Gas Expander Process

- (1) An gas expander is a device for converting the energy of a gas or vapor stream into mechanical work as it expands through the gas expander.
- (2) Since the amount of heat transfer between the expanded gas and the atmosphere is very small owing to the rapid development of the expansion, this process is considered to be nearly isoentropic. According to the first law of thermodynamics, the internal energy in a working fluid decreases by the amount of work done by the working fluid. Hence, as a result, the temperature of the fluid will be considerably lower. Namely, the gas expander can be used as a cold heat producing device (refrigerator) and/or as a work producing device.

2.3 Classifications and Applications**2.3.1 Process Application**

The most common method of extracting and utilizing expander power is to connect a centrifugal compressor directly to the shaft of the gas expander.

Instances of gas expander applications in ethylene plants are shown on Fig. 1 and 2. In Fig. 1, the same gas that has passed through the expander, enters the compressor. In Fig. 2, the gas stream to the compressor is different from the one which passes through the expander.

Even though the power available in the gas expander is sufficient for utilization, if there is no gas to be compressed by using the power, such a device as an electric power generator is connected to the gas expander to recover the power. Fig. 3 and 4 show the outline of such a flow.

Table 1 summarizes typical process applications which utilize a gas expander.

Table 1

Process Application	Role of Gas Expander		Type of Driven Equipment
	Power Recovery	Low-Temp. Recovery	
FCC	×	—	Generator/Compressor (*3)
Process Effluent Gas (*1)	×	—	Generator/Compressor (*3)
LNG Cold Power Generation	×	—	Generator
Blast Furnace	×	—	Generator
Light Hydrocarbon Process (*2)	×	×	Compressor/Generator
Air Separation (Large)	×	×	Compressor
Air Separation (Small)	—	×	Brake

Note (*1) : Nitric Acid Plant, Terephthalic Acid (TPA) Plant, Ethylene Oxide Plant, Phenol Plant, etc.

Note (*2) : Ethylene Plant, LNG Plant, LPG Plant, etc.

Note (*3) : Helper drivers (electric motors, steam turbines) may be used.

2.3.2 Type of Gas Expanders

- (1) Gas expanders can be classified as either velocity type or displacement (screw) type.

Velocity type gas expanders can be further classified into two types according to gas flow passage pattern when it expands in the machine, i.e., "axial flow" and "radial inflow".

In general, axial flow gas expanders are used for relatively large flow/power applications, and radial inflow gas expanders for small flow/power applications.

Typical applications of axial flow gas expander are such as FCC, Process Effluent Gas, LNG Cold Power Generation and Blast Furnace.

Radial inflow gas expanders are used for Air Separation, Process Effluent, LNG Cold Power Generation and Light Hydrocarbon Process. One advantage of axial flow type over radial inflow type is that efficiency drop under turndown flow operations is relatively low.

Displacement (screw) type gas expanders are mainly used for small capacity applications, and one of their major applications is energy recovery from waste (low pressure and temperature) steam in various plants.

- (2) From overall constructions, the gas expanders which are commercially available, can be classified into the six types:

- Multi-stage centrifugal compressor type : Radial inflow
- Single-stage overhung rotor compressor type : Radial inflow
- Close-coupled expander-compressor : Radial inflow
- Back-pressure steam turbine type : Axial flow
- Overhung axial flow : Axial flow
- Screw type : Displacement

- (3) The single shaft expander-compressor type is commonly used for Air Separation and Light Hydrocarbon Process. The expander and compressor have single stage overhung radial flow impellers and they are directly connected together via a solid shaft.

2.3.3 Gas Expander Manufactures

Table 2 summarizes reputed gas expander manufacturers with their typical applications.

Table 2

Manufacture (Country)		Expander Type (*1)	Applications (*2)
Atlas Copco Energas	(Germany)	RI	LHC, AS, etc.
Dresser Rand	(USA)	A	FCC, BF, NA, etc.
Ebara Corporation	(Japan)	A	FCC
Elliott Company	(USA)	A	FCC, BF, etc.
GHH Borsig Turbomaschinen	(Germany)	A/RI	FCC, BF, NA, TPA, etc.
IHI	(Japan)	RI	AS, PTA, LNG, etc.
Kawasaki Heavy Industries	(Japan)	A	BF, etc.
Kobe Steel	(Japan)	RI/S	TPA, NA, LNG, PH, etc.
Mafi-Trench	(USA)	RI	LHC, etc.
Mannesman Demag	(Germany)	RI	TPA, etc.
Mitsubishi Heavy Industries	(Japan)	A	BF, LNG, etc.
Mitsui Eng'g & Shipbuilding	(Japan)	A	TPA, EO, PH, BF, etc.
Nuovo Pignone	(Italy)	A	FCC, NA, etc.
Rotoflow Corporation Inc.	(USA)	RI	LHC, AS, etc.
Cryostar	(Switzerland)	RI	AS

Note (*1) A : Axial Flow
RI : Radial Inflow
S : Screw

Note (*2)	AS	: Air Separation
	BF	: Blast Furnace
	EO	: Ethylene Oxide
	FCC	: Fluid Catalytic Cracking
	LHC	: Light Hydrocarbon Process
	LNG	: LNG Cold Power Generation
	NA	: Nitric Acid
	PH	: Phenol
	TPA	: Terephthalic Acid

3. DESIGN

3.1 Details of Gas Expanders

3.1.1 Gas Expander Control

Since the gas expander play a part of process function, it is normally furnished with a duty control device such as an inlet gas throttle valve and/or variable flow nozzle in order to regulate its rotating speed and/or process parameters such as pressure, temperature and flow in the process streams. This is done by applying an instrument air signal to an air diaphragm actuator, which adjusts the openings between nozzle segments. Regardless of the degree of change made to the nozzle openings, the resulting high velocity streams are directed into the turboexpander wheel at the correct angle. Fig. 6 shows a typical variable flow nozzle of radial inflow gas expander. The variable flow nozzle should be matched with the rotor to give high efficiency over a wide range of flow rate (normally 65% ~ 110% of design as shown in Fig. 7).

Expander control scheme is constructed depending on process application, type of gas expander, type of driven equipment, type of helper driver, etc. Figures 1, 2 and 8 show examples of expander control schemes. Expander speed control is not always furnished. Where a helper driver is installed, the speed regulation is achieved by the driver.

3.1.2 Safety and Protection Devices

Typically the following safety and protection devices should be furnished on each gas expander.

- Overspeed Trip
- High Shaft Radial Vibration Trip
- High Shaft Axial Displacement Trip
- High Bearing Temperature Trip
- Low Lube Oil Pressure Trip
- Seal Failure Trip or Low Seal Gas Pressure Trip
- Alarms for Mechanical Parameters
- Alarms for Process Parameters

However, the extent of safety and protection devices should be referred to the project specifications for machinery and the manufacturer's recommendations.

3.1.3 Shaft Seals

(1) Gas expanders are furnished with shaft seals to prevent process gas from leaking out to the atmosphere. The type of shaft seals should be specified in consideration of the nature of the gas, i.e., pressure, temperature, toxicity, flammability and corrosiveness. The following seals are normally used:

- Oil Film Seal
- Mechanical Contact Seal
- Labyrinth Seals
- Dry Gas Seal

- (2) Oil film and mechanical contact seals require supply of pressurized lubrication oil. The seal oil is often supplied from the equipment bearing lubrication oil supply system. The following attentions should be paid where the seal oil is used.
- Oil migration into the process system should be prevented, which is normally achieved by the use of buffer gas injection to the seals.
 - Outwardly flowing seal gas from the expander and compressor seals will enter the casing and mix with the process gas. Seal gas flowing inwardly across the labyrinth seals will enter the expander and compressor sides of the bearing housing where it mixes with lube oil.
 - Because pressure within the expander and compressor sides of the bearing housing are too high for the lube oil/seal gas mixture to be returned directly to the atmospheric reservoir, high pressure drainers are used to receive the discharging mixture.
 - Seal gas is separated from the lube oil within the high pressure drainers. The seal gas separated from the lube oil is vented in a controlled manner, usually through a mist eliminator, at the top of the drainers to the flare system.
 - Some seal gas will enter the center section of the bearing housing, where it will flow along with the lube oil to the reservoir. In the reservoir, the seal gas is separated from the lube oil and vented through a mist eliminator to high vent system.
 - If heavy hydrocarbons are present in the seal gas, there is a tendency for a accelerated dilution of the viscosity of the lube oil, especially at startup and in the high pressure expanders. Frequent checks of the lube oil viscosity is required.
- (3) Where the process gas is not flammable, labyrinth seals may be used. Most of FCC, Blast Furnace and Process Effluent Gas expanders utilize labyrinth seals. Gas leakage to the atmosphere can be prevented with multi-stage labyrinth seals and buffer air injection to the seals. Where air migration into the process system is not desirable, a vacuum device such as steam ejector and vacuum pump may be furnished with multi-stage labyrinth seals.
- (4) There are three types of dry gas seals according to physical arrangement. Seal type should be properly selected depending on process gas.

Dry Gas Seal Type	Type of Process Gas
Single Seal	Non-flammable, Non-toxic
Tandem Seals	Flammable
Double Seals	Flammable, Toxic

It should be noted that dry gas seals must be kept clean and dry, and require external buffer gas to the seals.

3.1.4 Bearing and Lube Oil System

- (1) Most of gas expanders are furnished with hydrodynamic radial and thrust bearings. The bearings are lubricated with forced feed turbine oil.
- For a close-coupled expander-compressor, to protect the thrust bearings from over-load and damage, the units are provided with an automatic thrust balance system. It senses hydrodynamic oil pressure on the front and back thrust bearings, compares them, and adjusts the pressure of a cavity behind the compressor wheel so that the rotor system remains in balance position (center). The system provides continuous thrust adjustments by varying pressure of the cavity behind the compressor wheel. An increase in the compressor thrust bearing pressure will cause the automatic thrust balancing valve to open, which relieves the cavity pressure. An increase in the expander thrust bearing pressure will cause the automatic thrust balancing valve to close and build up pressure in the cavity.

- (2) The lube oil supply system should normally be designed in accordance with API-614, and the following auxiliary equipment should be furnished:
 - Oil reservoir
 - Main oil pump
 - Standby oil pump
 - Twin oil coolers
 - Twin oil filters
- (3) For a close-coupled expander-compressor, two sets of multi-lobe or tilting pad type radial bearings are installed in the middle of the rotor shaft. To prevent oil migration into the process system, external seal buffer gas is injected between the bearings and expander/compressor impellers. Since the bearings are exposed to the seal buffer gas, the bearing drain oil will contain the gas. The lube oil circulation system is designed to allow this situation, i.e., the whole system may be fully enclosed, pressurized and/or purged with inert gas. Often synthetic oil or turbine oil with high viscosity grade is used for hydrocarbon applications. Fig. 9 shows a typical flow diagram of expander-compressor lubrication system.
- (4) Occasionally, pressurized oil system is adopted. It is the system that the system is entirely pressurized including oil reservoir. This system is advantageous when the system pressure is relatively high since the load required to pump the oil is only for pressurize the differential pressure.
- (5) Turboexpanders may be furnished with active magnetic bearings.

3.1.5 Expansion of Stream Running in Mixed Phase at Discharge

- (1) If a gas enters an expander at or near the dew point, the expander will be operated in the condensing range. An instance of this flow is shown on Fig. 8.
- (2) In the case of expanders intended to handle condensing streams, the blades are designed to be parallel to the vector of the force which the fog droplets have in the fluid.
- (3) As a result of this, the fog particles in the fluid do not drift toward the wall or collect; namely, they will not affect the efficiency or erode the blades.
- (4) Theoretically, it is said that even if 100% condensation occurs in the rotor, the problem of erosion will not arise at all. Generally, however, 20 wt% condensation or so is a criterion in which case little efficiency drop may occur due to the condensation. If the condensation exceeds 20 wt%, the matter shall be reviewed and discussed with the rotary machine engineer in charge and/or the manufacturer.
- (5) The precautions concerning the outlet piping of expander are given hereinafter. Study carefully so that no "Slug Flow" may be caused in the piping since the foregoing flow may have an adverse effect on the expander. This purpose can also be met by installing two or more branch pipes and providing each branch pipe with a valve.
Further, the adoption of a down-flow type outlet pipe can also serve this purpose. In this case, the fluid can, if necessary, be sent to other equipment by sending the fluid by down-flow to the separators, and then, to the next equipment upon dividing the fluid into vapor and liquid.

3.1.6 Expansion Ratio (for Radial Flow Expander)

- (1) Generally, high efficiency can be obtained at an expansion ratio of 3.0 - 4.0 for natural gas application.
- (2) To increase the amount of refrigeration per unit quantity of expanding gas, it is necessary to use a large expansion ratio. In the case of one-stage expanders, if the expansion ratio exceeds 10.0, the efficiency will lower (See Fig. 12). If two-stage expanders are used, the expansion ratio can be determined for a value up to 35.0. Even at such a condition as an expansion ratio of 35.0, the efficiency can be maintained at about 80% if two - stage expanders are used.

3.1.7 Length of Discharge Line Straight Portion

A straight run is normally required immediately before the inlet and/or after the outlet of gas expander. The required straight length is normally between 3 or 5 times of nominal piping diameter, but should be confirmed by the manufacturer. Such a requirement should be clearly indicated in the relevant P&I diagram, or the outline (general arrangement) drawing.