Research Paper

Development and application of screw expander in natural gas pressure energy recovery at city gas station

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HIGHLIGHTS

- The natural gas screw expander keeps running below its critical speed.
- Mechanical seal with cryogenic materials was adopted and proved to be reliable.
- Rolling bearing can be simply selected due to its low rotation speed.
- Stable performance under variable gas conditions can be guaranteed easily.
- The natural gas screw expander is suitable for energy recovery in CGS.

ARTICLE INFO

ABSTRACT

There is a tremendous energy loss in the process of natural gas delivery by pipes. The energy lost in the pressure reduction process can be first transformed into mechanical energy and then further converted into electricity by a generator. In this study, an oil free twin screw expander was designed and applied for the nature gas energy recovery at a city gas station for the first time. And the critical speed of the rotors, the seals and bearings were discussed and presented in the design, which was proved that the system designed with the twin screw expander is much simpler without challenges of the sealing and bearing selection facing in the traditional turbine expander used in the CGS. Finally, the feasibility and simplicity of using the screw expander in natural gas energy recovery and power generation were proved through its stable running performance at site. The twin screw expander, therefore, could make up for the defects of the traditional turbine expander at a high rotation speed applied in the samilar area, and turned out to be an effective way to recover the pressure energy from the natural gas.

1. Introduction

Nowadays, natural gas has become the main supplement to the energy source of oil and coal. There are generally two main methods for the long-distance transportation of the natural gas: transmission of gas in high-pressure pipelines and shipping the liquefied natural gas (LNG), which aims to minimize the specific volume of gas and consequently reduces the cost and energy demand in the transport and storage processes [1]. In all these high-distance transportation methods, the local distribution pipelines are used for supplying the natural gas to end consumers, which operates at a much lower pressure compared to the transmission systems. For example, the natural gas is delivered to the city gas network after the pressure regulation in a city gas station, where the gas pressure is decreased from 2.5–5.5 MPa to around 1.7 MPa or even to 0.4 MPa through a throttling valve or a pressure

control valve. During this pressure regulation process, significant pressure energy is lost and there is also a potential risk for the safe operation in pressure regulation because of a quick temperature decrease in pipes and equipment [2]. However, such energy loss and operational risk could both be reduced if there is a proper solution for recovering the pressure energy, which would further increase the energy utilization rate in the natural gas system.

The related research of utilizing pressure energy through the gas distribution process has been studied in USA, UK, Canada, Russia and other countries since the 1980 s. The previous studies have shown that the research on the recovery of gas pressure in gate stations mainly applied the turbo expander. He and Ju [3] designed a liquefaction process to utilize the pipeline pressure energy and calculated the available pressure energy in the gas pipeline at different pressures. Marco and Badami [4] experimentally investigated the energy-saving

potential and the economy of the turbine applied in a natural gas station. Zabihi and Taghizadeh [5] found the obstacle to the application of the turbine in recovering natural gas energy in city gas station is the large variation in the flow rate and the high equipment cost. Neseli [6] analyzed the change of natural gas flow rate and pressure in a gas station and found it was able to obtain an electricity profit around 4113.03 MWh/a by replacing the throttle valve with turbine expander. Zehtabian and Saffar-Avval [7] found that the fluctuation of inlet flow rate had a great impact on the performance of the turbine in a natural gas station under a flow rate of 20000 Nm³/h. The efficiency reached 67.79% under an actually operational flow rate, which was 80% at the rated flow rate. Howard et al. [8] examined the efficiency of a turbine generating system in a small city gas station in Canada and found that the system efficiency was increased by 10% through adding a set of fuel cells.

However, there are some challenges in the application of turbine expander for recovering energy from natural gas pressure in the city station, which can be concluded as follows:

(1) It is difficult for the medium or small scaled station.
(2) The required amount of the natural gas supply is different in different seasons, day and night or different single hours. This also has a negative impact on the application of the turbine expander in energy recovery system at the natural gas city station.
(3) The recovery cycle of the project investment is long by using the turbine expander. Because the turbine expander used in the CGS needs a complex shaft sealing system and a non-conventional bearing, which means the equipment cost and maintenance cost are very high.

For reasons mentioned above, the energy recovery of natural gas pressure by the turbine at CGS is restricted. This paper proposed and designed a new type of drive machine for natural gas pressure recovery. Theoretical analysis has been carried on the rotor dynamics, sealing system and bearing selection etc. Besides, the mechanical properties of this natural gas screw expander are demonstrated by the steady running performance in a natural gas station.

2. Design of the natural gas screw expander for a CGS

In this paper, a natural gas screw expander is designed for specific working conditions of a natural gas gate station in China, which can be set in parallel with the original pressure regulating valve of the gate station for the natural gas pressure energy recovery. The primary decompression system consisted of two pressure control units with the same capacity as shown in Fig. 1. The pressure of upstream inlet gas is about 0.78 MPa (g) while the flow rate of the gas is 10000 Nm³/h. The natural gas is heated in a preheater after passes through a filter to wipe off the impurities. The pressure of the natural gas is then depressurized to 0.35 MPa (g) by the cut off valve and regulator valve. After the depressurization, the natural gas is distributed out. Moreover, more valves such as vent valve and globe valve are set forward and backward to work as security measures. The chemical components of the natural gas in this CGS are listed in Table 1.

Table 1
Chemical Components of the natural gas from the gas station.

Name	Molecular formula		Mole number	Unit
Methane	CH4		94.9514	%
Ethane	C2H6		2.5857	%
Propane	C3H8		0.4257	%
Butane	n-C4H10		0.0757	%
Iso-Butane	i-C4H10		0.0743	%
Pentane	n-C5H12		0.0100	%
Iso-Pentane	i-C5H12		0.0286	%
Nitrogen	N2		0.6029	%
Carbon Dioxide	CO2		1.2457	%
Total	3000	3000	100.0000	%

Table 2
Major design parameters and components of the natural gas screw expander.

Parameter/Component	Specification
Flow rate	10,000 Nm³/h
Inlet pressure	0.78 MPa(G)
Inlet temperature	50 °C
Outlet pressure	0.35 MPa(G)
Rotation speed	1500 rpm
Rated power	150 kW
Sealing type	Mechanical seals
Bearing type	Rolling bearing

The information of the major design parameters and components of the natural gas screw expander are listed in Table 2.

2.1. Critical speed calculation of the rotor

According to API619 [9], the screw rotors can be regarded as a rigid shaft as the speed is below the critical value, which is different from the turbine machinery under a high speed, so only the torsional analysis is required in the design of the screw rotor shafting. However, the shafting of the screw expander generator generally composes of a gear box or a motor by coupling components and forms a complex shafting system. Therefore, a large vibration of the whole unit will occur due to the torsional resonance when the mass center of each part is not strictly on the rotating axis, even if there is no lateral interference. This means that the torsional natural frequency and modal analysis of the natural gas screw expander generator shafting are necessary to guarantee a steady running of the system, where the shafting calculated should consider both the screw rotor and the generator rotor simultaneously as well as their connecting assembly.

The number of critical speed is equal to the number of concentrated mass in a discrete rotation system with finite concentrated mass as the critical speed is dependent on the elasticity and mass distribution of the rotor in the calculation of the natural frequency of shafting. In practical engineering application, critical speeds of lower orders are critical because they may cause severe resonance of the shafting. For a rigid rotor whose working speed n is lower than its first-order critical speed, it
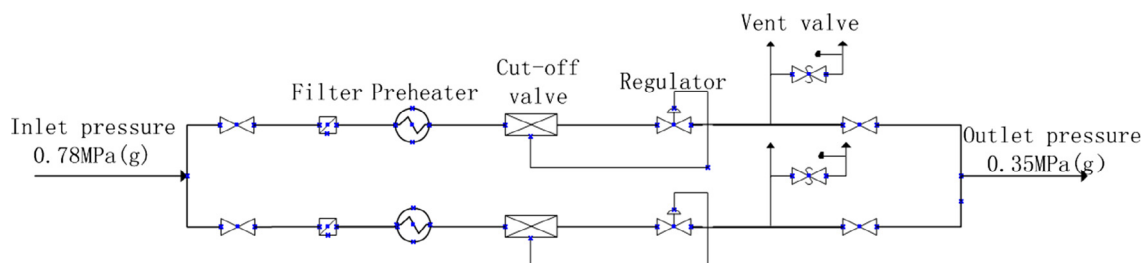

Fig. 1. The diagram of the natural gas station decompression system.