New projects developed by COMOTI in gas industry

Marian Nitulescu
Dipl. Engineer COMOTI, 220 D Iuliu Maniu Bd., sector 6, cod 061126, OP 76, CP174Bucharest, Romania

Valentin Silivestru
Scientific Researcher 1, Dr. Engineer President General Director, COMOTI, 220 D Iuliu Maniu Bd., sector 6, cod 061126, OP 76, CP174Bucharest, Romania

Niculae Toma
Dr. Engineer COMOTI, 220 D Iuliu Maniu Bd., sector 6, cod 061126, OP 76, CP174Bucharest, Romania

Cristian Slujitoru
Dipl. Engineer COMOTI, 220 D Iuliu Maniu Bd., sector 6, cod 061126, OP 76, CP174Bucharest, Romania

Valentin Petrescu
Master. Engineer COMOTI, 220 D Iuliu Maniu Bd., sector 6, cod 061126, OP 76, CP174Bucharest, Romania

Mihai Leahu
Director research and design department, Transgaz, County Sibiu, Piața C. I. Motaș, Nr. 1, CityMediaș, Cod 551130

Ciprian Oniga
Chief research dipl. engineer, Transgaz, County Sibiu, Piața C. I. Motaș, Nr. 1, CityMediaș, Cod 551130

Gheorghe Ulici
dipl. Engineer, Transgaz, County Sibiu, Piața C. I. Motaș, Nr. 1, CityMediaș, Cod 551130

Abstract. The paper aims to present two new projects developed by the Romanian Research and Development Institute for Gas Turbines (COMOTI) in partnership with City University of London and GHH-Rand Germany, in the field of screw compressors/expanders. COMOTI passed, in recent years, from being a GHH-Rand licensed manufacturer for a range of oil-injected screw compressors, of CU type, to a new phase of range diversification, approaching screw compressors with a maximum discharge pressure of 45 bara. So, in cooperation with City University and GHH-Rand we design, manufacture and test, with air, in COMOTI test bench the new type of screw compressor named CHP 220. Also, the cooperation with GHH-Rand has resulted in the design, manufacture and air testing on the test bench, and then gas testing – in a gas compression station - for an electric generator driven by a screw expander. This paper presents how the tests were carried out, the experimental data and the interpretation of results.

1. Introduction

From the beginning we want to emphasize that the long-term strategy of COMOTI is to build high efficiency, high returns and original solutions, technological and constructive, applied in engines construction, aviation systems and equipment - the Institute has a tradition of over 20 years - by creating and developing efficient products and technologies, especially requested by the oil and gas Companies. Trying to meet the demands / estimates on the evolution of the operating parameters of the gas stations, COMOTI developed two new projects:

- Screw compressors, which are positive displacement compressors and can find an increasing use in the gas industry and beyond, due to their advantages. So far, we have realized, under license from GHH-RAND, screw compressors with oil injection with a maximum flow rate of 3000 Nm³/hour and a discharge pressure of maximum 30 bara. We emphasize that the good working relationships we had with the GHH-RAND company ended by allowing us to manufacture under license - since April
2010 - the CU screw compressors family. Requests / signals from potential beneficiaries required addressing the need to design a new family of screw compressors, with oil injection, capable of developing a discharge pressure of 45 bar with flow rates up to 5000 Nm3/hour. This paper presents the experimental test phases – for the first screw compressor with discharge pressure up to 45 bar-type CHP220, realized by COMOTI in cooperation with City University –London – the basic rotor design, and GHH-RAND for manufacturing rotor pair. Continued research and development have allowed this type of screw-compressor to find a market position, diversifying its size range in the last decade, if we refer to other types of the compressors (centrifugal or reciprocating compressors).

To reduce the gas pressure in the regulating and measurement stations from the national piping network (with pressures up to 40 bara), lamination valves are used, usually heated to reduce the pressure from the national piping network to the local piping network. This leads to a significant loss of "green" energy that can be recovered through the efficient use of the differential pressure in the expander. The aim is to replace the rolling valves and regulators with a screw turbine which, through the adiabatic expansion of gases, produces a clean and usable energy. COMOTI developed an efficient equipment, a power conversion equipment that converts gas expansion in green electricity. This unique group works using the oil-injected screw technology. After years of research and experimentation, COMOTI has developed a new configuration of turbine screw expander with oil injection ( an advantageous solution for relatively small flows) that will have all the screw compressors advantages: high efficiency, due to the compression evolution nearly isothermal, low maintenance costs thanks to very good reliability, fewer moving parts, and not in the least, competitive price. The solution has not been studied in Romania and is not applied to any plant or TRANSGAZ or ROMGAZ stations. Another advantage of using such equipment are, besides producing green electricity, the natural gas availability to other consumers, reducing the amount of CO2 released into the environment.

2. TEST with air, on COMOTI test bench for CHP220

We do not propose to analyze in detail the data related to the design, manufacture and completion of the compressor. But, in the case of the tests with a new type of compressor, conducted by COMOTI in cooperation with City University and GHH-Rand, we consider that it is necessary to provide data on the gas dynamics and the constructive parameters of the compressor CHP 220:

- oil flooded screw compressor that compresses a normalized flow of 5000 Nm3/h of natural gas from an admission pressure of 4,5 bara to a discharge pressure of 45 bara, when rotating at 1430 rpm,

-roter design summary:

- 4/5-306 mm rotor diameter male/248,8 rotor diameter female, 413,1 mm length, L/D =1,35
- “N” rack generated Profile, UK Patent 9610289, PCT World 97/43550, US6,296,461, EP 0898 655
- Wrap angle 300°
- Displacement 17,38 dm3/rot, meaning 15oo m3/h at 1430 rpm

The Performance chart of the 4/5-306 Compressor on gas, given by City University [7]
To retrieve the very high load generated by pressure force on bearings, we choose the solution with balancing piston and radial/four point contact bearings, Explorer type – specially developed for application in screw compressors [8]. The rotors - see fig. 1 - were made of steel and were manufactured by grinding by GHH-Rand and therefore ensuring excellent precision and contact. The L/D, where L=length of rotors and D= male rotor diameter, has an optimal value - 1.35 [7], and so, the deflection is minimized providing compactness for the compressor. Because of the high discharge pressure – over 27.5 bar [4] – the housings were designed to be manufacture from steel. The structural integrity was verified by stress analysis, and after manufacture hydrostatic test was done at 76 bar. For safe and reliable operation a high quality dual seal was installed. After the manufacturing of the parts, during compressor assembly, each component was inspected to ensure that they have been cleaned and they are free of foreign material, corrosion products etc. After assembly, the compressor is ready for tests. The test was done on COMOTI's test bench, with air. Because this is a prototype, we intend to compare the theoretical - see fig. 2 - with measured parameters(for discharge pressure of 8.5 and 12 bara, City University have calculated the prediction parameter –[7]).

Figure 1. Rotors

The instrumentation scheme of the test bench is shown in fig. 3, and respects the requirements stipulated in API619 and ISO1217. The parameters to be measured for the estimated performance of the compressor will be: compressor inlet/discharge temperature and pressure; speed of the male rotor; power of the electric motor driver; pressure/temperature of oil after the oil cooler; differential pressure, pressure and temperature across the venturi nozzle.
in/out temperature for water, in the oil cooler; oil rates, in each oil point injection (seal, inlet bearings, injection, discharge bearings); pressure of oil in each oil injection point; atmospheric pressure and atmospheric temperature.

**Figure 3.** Instrumentation scheme of the test bench

All measurements were obtained from electrically generated signals derived directly, respectively, from the speed, pressure, temperature and flow rates measurements. All the installation parameters (4-20 mA analogical, 0-24 Vcc digital) are supervised by a Programmable Logic Controller. The values of parameters are recorded at a certain rate of time in computer memory (25 μs). The compressor process evolution was analyzed through parameter values data acquisition. Also, the parameters can be viewed in real time on the operating panel, which contains a series of screens that allow an operator to monitor the parameters.

In Fig. 4 – there is a photo of the test bench, with the compressor installed in it.
We can see: the electric motor driven; the multiplier; the compressor unit; the oil cooler/oil filter; the oil pipeline; the air pipeline suction and discharge; instrumentations for pressures, temperatures, flows, rotation; -air/oil separator etc.

During the course of the test, the temperatures of the compressor surfaces were measured automatically with a Fluke monitor - Fig. 5.

The test data were obtained, with atmospheric pressure at inlet and discharge pressures of 8.5, 12 and 15 bara. In Fig.6 we present print screens with the parameters at different moments of the tests. The maximum discharge pressure realized on the test bench was 36 barg (print-screen on the right side).

Using these parameters, and the relations mentioned:

- $k =$ adiabatic efficiency; $R =$ gas constant [kJ/kgK]; $Ta =$ suction temperature [K]; $\gamma =$ compression ratio; $G =$ mass flow [kg/s]; $m_o =$ oil flow rate [kg/s]; $c_p =$ specific heat gas [kJ/kg K]; $c_v =$ specific heat oil [kJ/kg K]; $\Delta T =$ differential temperature between suction and discharge for gas [K]; $\Delta T_o =$ differential temperature between suction and discharge for oil [K]
\[ \eta_v = \text{volumetric efficiency} = \frac{Q_{\text{measured}}}{Q_{\text{theoretic}}} \]

We elaborate the experimentally measured performance, as shown in Fig 7:

**Figure 7.** Experimentally measured performance

Given the conditions in which the experiments were conducted, the technical constraints that had to be taken into account, while comparing with recommendations of [5] - Annex C - we can say that the values of these parameters are as expected and in acceptable limits.

### 3. Test for screw expander

The screw expander - electrical generator is a viable and economical solution for recovery the lost gas expansion energy, in the gas pressure reduction station.

In order to reduce gas pressure in the gas pressure reduction station and the quantity on main pipelines, lamination valves are used, usually heated, which allow the reduction of pressure from the transport pressure to distribution pressure. This leads to a significant loss of energy "green" which can be recovered by decreasing pressure in the expander who drives the generator.
I.N.C.D.T. COMOTI has developed an efficient equipment for the conversion of the expansion energy of natural gas into electrical “green” energy. This group unique operates using screw technology (screw compressor), with oil injection, which has been used for a long time to screw compressors.

The conversion of screw compressor - type CU 128 G - in screw expander was made by GHH Rand, COMOTI performed tests, both air - in COMOTI's test bench - and gas - in a pressure reduction station.

The nominal system operating regime for the electric generator - screw expander corresponds to the following parameters:
- pressure of the natural gas at the entrance of the expander = 20 bara;
- discharge pressure of the expander = 5 bara;
- screw expander EU 128 G , Vi=2.6 , n\textsubscript{male rotor} =3838 rot/min, i=2.559;
- electric generator type GSIF EX dllBT4 250 kVA; 400 V, 1500 rpm (brushless synchronous generator).

Advantages:
- High efficiency of the product is due to detent almost isothermal - by the injection of hot oil, gas temperature;
- Does not pump, essential advantage in variation of parameters of gas at the entrance to expander;
- minimum structure requirements, due to the direction of continue rotation and the rotor dynamic levelling;
- Low maintenance, due constructive simplicity.

Screw Expander was tested on the COMOTI's test bench, see Fig. 8, in a configuration determined by the possibility of providing a source of air (air intake - 3 compressors CU128G).

All measurements were recorded digitally and then transferred to a computer used for online processing.

The command and control system has the tracking function of the parameters of thermal, mechanical and electrical processes, during normal or transitional working processes, adjusting and keeping under control, by the course of the operation in complete safety. The system for the expander-generator is based on a numerical system monitoring and management PLC type Versa Max produced by GE Fanuc. It connects with the components of execution by relays, contactors, transducers, signal adapters.

Constructive solution of the command and control system takes into account the working conditions of the assembly expander-generator, the nature of gas and noise area from the point of view of danger of explosion.

There are 3 automation lockers ( 1 locker for expander, 1 locker for energy monitoring and protection, 1 supply locker and generator protection) where the operator can follow the operating status of the assembly screw expander-generator (are located outside in areas Ex.).

For fixing the speed of expander at the level of 1500 rmp was put into the circuit of the generator a ballast resistor variable in three-phase. By the value of this resistor and the implementation of an excitation voltage has been obtained stabilization around the 1500 rmp (the operation was done in a insularized regime).

During the test the flow being discharged from the three compressors is up to 2426 kg / h and the expander inlet gas pressure reaching 6.75 bar. Oil was heated at 70 °C and gas at suction of the...
expander at 60 °C. The maximum power obtained at generator was 51 kW (the expander power was 63.75 kW).

The tests confirmed the functionality of the equipment, tests on gas in gas reduction station will certify gas/generator parameters.

Experiments at Gas Reduction Station Onesti, see fig.9, were performed in the rpm range between 500 - 1500 rpm.

Figure 9. Expander-generator at Onesti

The technological scheme – see Fig. 10 – was designed and manufactured that:
- to ensure oil heating
- to ensure gas heating
- to ensure the integrity of the equipment in the station without affecting the normal operation;
- the control and PLC control equipment to ensure integrity in operation, process data collection and processing

Tests were conducted at the Gas reduction Station in two stages:
- in the first phase gas flow varied between 1470..2087 Kg / h, suction pressure in expander between 11..13.7 bar, obtaining an output power (expander shaft) between 27..77 kW
- in the second phase gas flow varied between 1400..4500 Kg / h, suction pressure in expander between 10..15.7 bar see Fig. 11 obtaining an output power (expander shaft) between 25..111.25 kW (see fig. 12)

Experimental curves obtained at different pressures and flows - not the nominal parameters, because these was station available parameters - show a close evolution estimates by GHH-Rand Germany.

Also, to stabilize the speed at 1500 rpm of the expander, a three-phase variable ballast resistance was placed in the circuit of the generator stator. The value of this resistance and an appropriate excitation voltage of the expander were stabilized at 1500 rpm, so the generator is ready for a possible coupling to the network.

Figure 10. Technological scheme
4. Conclusion

4.1 Screw compressor

The design of an oil injected screw compressor, with high discharge pressure - 45 bara - has passed the design and experimental phases. The compressor has undergone specific test production. Results can be considered normal for the test stage performed. The development of the tests stand for...
4.2 Screw expander

It has been proven the functionality of equipment. Given the stand conditions (maximum flow 2400 kg/h at a pressure of 6.75 bar) the power at turbine shaft reaches 63.75KW (pGen = 51 kW), the isentropic efficiency 0.7. We obtain a high discharge temperature (above 20 °C), which shows that we can achieve a diminished heating of the injected oil.

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