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DESIGN AND DEVELOPMENT OF AN OILFREE, HERMETIC HIGH PRESSURE COMPRESSOR

By

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ABSTRACT

This paper describes the concept and the design features of a new, oilfree, reciprocating high pressure compressor for technical gases. The compressor is unique in concept and design, and introduces various new design elements. A magnetic coupling makes the compressor hermetic and allows inlet pressures of up to 16 bar. A new kind of clearance seal in the high-pressure stages allows reliable oilfree compression up to 310 bar. Due to the mass balanced scotch yoke drive the compressor operates very smooth and almost vibrationless.

INTRODUCTION

The basic design concept of the OM-compressor presented in this paper is deducted from the small, oilfree high pressure compressor type OF presented four years ago. The OM-compressor is much higher in capacity (40^-110 Nm³/h instead of 3 Nm³/h) and pressure (310 bar instead of 200 bar). New design elements needed to be incorporated therefore. The compressor was particularly developed for use in NGV-refueling plants but can be used with other gases as well.

DESIGN CONCEPT

The DM compresses the gas oilfree from inlet pressures between atmospheric and 16 bar to outlet pressures of up to 310 bar. The basic DM-compressor is a 5-stage unit with the gas inlet into the crankcase; from there the gas passes the inlet valves of stage 1 which are arranged in the piston of stage 1. The compressor housing is pressure tight up to 16 bar. Different cylinder configurations (see Fig.6) allow to adapt the compressor to the required pressures.
The main design features are:

- Oilfree, hermetic, high pressure
- Direct drive, with magnetic coupling, no flywheel
- 4-cylinder cross arrangement with massbalanced scotch yoke drive
- Vertical shaft arrangement with compressor fixed and sitting on motor flange
- Aircooled, with fan on motor shaft end
- Small multiple plastic-plate valves type "SULTHANE®"
- 3 + 5 compression stages
- Piston sealing: piston rings in stages 1-3, clearance seals in stages 4 and 5

COMPRESSOR SET UP

The motor and compressor are arranged in vertical direction. The motor is bolted sideways on a steel frame and carries the compressor on the motor flange with the coupling lantern in between. The whole module is mounted on four rubber elements. The module also carries the interstage cooler, filters, separators and safety relief valves (see Fig.1) as well as the necessary instrumentation. The feature of this arrangement is the small footprint of the module and easy and comfortable access to all the components and to the compressor cylinders at eye level.

MAGNETIC COUPLING VERSUS SHAFT SEAL

An oilfree compressor with oilfree crankcase consequently demands an oilfree shaft seal which further needs to be leak- and maintenance-free for pressures up to 16 bar. These requirements can only be met by a magnetic coupling in place of the shaft seal.

The magnetic coupling has the following features:

- Oilfree, leak free, maintenance-free
- No transmission losses
- Simple
- It acts as a safety clutch: in case of an override of the coupling due to a compressor overload or a blocked drive, the electronic shuts down the motor using the signal from a sensor which checks the rotation of the compressor.

The coupling consists of two rotors with inserted permanent magnets of type NdFeB and a CF-plastic pot in between the two rotors, sealing against the compressor bearing flange. The inner rotor is fixed directly onto the compressor shaft and the outer rotor onto the motor shaft (see Fig.2).

The override torque of the magnetic coupling is approx. 2.5 times the nominal compressor torque.

The dimensioning of the coupling depends on the inertia of the compressor drive and on the torque curve of the compressor shaft. The scotch yoke drive with cross cylinder arrangement generates a torque curve with four similar peaks with 90° offset, which is particularly advantageous for the use of a magnetic coupling.
The override of a coupling results in an immediate stop of the compressor whereas the motor still turns. This situation leads to a rapid heating up of the coupling parts until the magnets exceed the demagnetization temperature at about 150°C; the coupling would then have to be scrapped. The rotation sensor prevents from this crucial situation.

SCOTCH YOKE DRIVE

The scotch yoke drive (see Fig.3) was chosen for several reasons:

- it allows a compact design
- it generates smaller side forces on pistons
- it keeps vibrations low due to nearly 100 percent mass balance
- it generates a more regular torque curve with four similar peaks with 90° offset

The difficulties of this drive are in the practical design of the yoke, slide block and linear roller bearings in between, which need a well defined and applied pretension in order to prevent the oscillating rollers from sliding. A special grease is applied to the bearings. The whole yoke assembly is sealed with two plastic covers on either side, which protect the bearings from dirt penetration and loss of lubricating grease. The shaft with only one crank devides into two pieces. It runs on a sealed ball bearing at the bottom and a sealed roller bearing at the top.

PISTON SEALING

The pistons of the first three stages with relatively moderate pressures are sealed with slit piston rings from PTFE- or PEEK-compounds depending on pressure and type of gas. The guide rings on the guide pistons and pistons stage 1 are of the same material. The cylinder sleeves are all from oxynitrated® C-steel.

The high pressure stages 4 and 5 have so called clearance seals with a smooth piston floating in a smooth cylinder with a small radial gap of approx. 3 μm in between. A small well defined leakage flows through the gap back into the crankcase of the compressor. The leakage loss is typically a few percent of the flow rate. This design needs to comply with several conditions which are all crucial:

- piston and cylinder have the same small thermal coefficient of expansion
- the material combination is tribologically suitable and has low wear characteristics
- the materials are chemically inert resp. corrosion resistant
- no side force is induced into the piston

Fig.4 shows the patented design of a clearance seal. The piston core carries PEEK-sleeves which are pressed onto. The piston rod is a tilting pin with sphere-shaped ends which accommodates misalignment and transverse movement between piston and drive part without inducing any side force into the piston. Clearance seals with hard material combinations like hardmetal, ceramic or coated steel might also be suitable but are not as „good-natured“ in case of a failure.
VALVES

Multiple plastic-plate valves (see Fig.6) type “SULTHANE®” are used in two sizes on suction and discharge side in all 5 stages. The valve bodies are from GF-PEEK. The spiral shaped flat spring pushes the valve body at the centre slightly against the valve seat. These valve bodies are used in numbers of 24 for stage 1 and of 2 for stage 4 and 5 each, for example.

CYLINDER CONFIGURATIONS / COMPRESSOR DATA

The basic compressor is a 5-stage compressor (type D5M212) with the cylinder configuration according to Fig.6 for inlet pressures between atmospheric and 500mbarg. Other cylinder configurations as in Fig.6 allow operation with higher inlet pressures.

Table 1 shows the data of the basic 5-stage compressor, and table 2 the flow rates of the 3 compressor types.

EXPERIENCES

The prototypes have been tested under laboratory-conditions on Nitrogen for more than 10'000 hours of operation. A few compressors are operating in Natural Gas refueling plants (the first one since Oct.96), one is operating in our Hydrogen testbed since Febr.98.

COMPRESSOR PACKAGE AND CONTROLS

The compressor module together with the E-box, LP-and HP-components, are enclosed in a weather-proof package. The package allows easy access to all the components and reduces the sound emission level (which is mainly from the fan!) to 65 dB(A) in 1 m distance.

A microprocessor based electronic system controls and monitors all the relevant process data and events and allows communication via 3 different serial interfaces. It allows remote monitoring via modem and PC. The remote monitoring is an important issue for an effective customer and service support system.

CONCLUSION

After several years of development and testing, the first “pilot series”-compressors have been installed and are operating successfully. The tests proof the concept and show the potential and also the limits of some new design elements. The next step will focus on extending the maintenance interval and on applications with gases like Air, Ar, He, Ne, H2 etc.
Fig. 1 compressor module

Fig. 2 magnet coupling

Fig. 3 scotch yoke drive
Fig. 4 piston/cylinder stage 4/5: clearance seal

Fig. 5 valves: type "Sulthane"

Fig. 6 types / cylinder configurations

Table 1: data, type D5M212

<table>
<thead>
<tr>
<th>Stage</th>
<th>Description</th>
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<tbody>
<tr>
<td>1</td>
<td>2 * 120 mm diameter</td>
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<tr>
<td>2</td>
<td>85 mm</td>
</tr>
<tr>
<td>3</td>
<td>45 mm</td>
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<tr>
<td>4</td>
<td>25 mm</td>
</tr>
<tr>
<td>5</td>
<td>16 mm</td>
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<table>
<thead>
<tr>
<th>Stroke</th>
<th>Speed</th>
<th>Suction Pressure</th>
<th>Discharge Pressure</th>
<th>Power</th>
<th>Noise Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>50 mm</td>
<td>1450 RPM</td>
<td>atmos. to 16 bar</td>
<td>max. 310 bar</td>
<td>400/690 V, 50 Hz, max. 30 kW</td>
<td>65 dB(A) at 1 m distance</td>
</tr>
</tbody>
</table>

Table 2: flowrate for Nitrogen at 20°C:

flowrate Nm³/h vs suction pressure bar (abs)