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Comparison of energy-efficiency and size of portable oil-free screw and scroll compressors

Olly Dmitriev, Prof. Ian MacDonald Arbon

Vert Rotors UK Ltd, Edinburgh, United Kingdom

olly@vertrotors.com

Abstract. This paper presents test data and evaluates if conical screw compressors can become a preferred alternative to scroll compressors in small oil-free duties from 0.04 to 15kW. The conical screw compressor is a new modification of the conventional screw compressor. A 2kW water-injected conical compressor demonstrated a 34% better energy efficiency than a scroll compressor of similar capacity. At 8 bar(g) load, the conical machine used 13% more energy and produced 42% more flow. Size of the conical screw package is 46% of the scroll package. The miniature conical screw package, at 40W rated power, achieved a pressure of 8 bar(g) in water-injected operation. It can be concluded that the conical screw compressor would be an attractive alternative in micro and small oil-free applications.

1. Introduction

Reducing power consumption for oil-free compressors is crucially important as electricity consumption typically represents up to 80% of the total lifecycle cost of the compressor. Furthermore, transmission losses may be reduced by replacing large compression plant with smaller compressors closer to end-users. However, these small compressors need to demonstrate high energy efficiency.

High energy efficiency in oil-free air is achieved with water-injection. It is known from other compressor manufacturers that compression with water-injection provides around 20% energy saving in comparison with dry-running, or adiabatic compression.

Water injection has become a standard option in compressors for the medical and food industries, with larger screw machines from 15 to 110kW. Examples include single screw compressors from CompAir (DH series, from 15kW to 110kW), and twin-screw machines from Atlas Copco (AQ 15-55 VSD, from 15kW to 55kW). However, in smaller sizes both twin-screw and single screw machines have not been able to achieve the required efficiency, due to high leakage through clearance in the “blow hole”, which is a design feature of such compressors [1]. Typically, this leakage is reduced by injecting oil into the compression chambers. Since the kinematic viscosity of water is two orders of magnitude lower than that of typical compressor oil, water does not provide the level of sealing required by the twin-screw and single screw compressors[1].

[1] At 40 °C, water has a kinematic viscosity of 0.658 mm^2/s, typical screw compressor oils have kinematic viscosity in the range of 32-64 mm^2/s [2,3]

Because of this limitation, the market for portable oil-free air compressors <15kW is not served by screw compressors. Instead, this market is typically served by dry-running (adiabatic) scroll or reciprocating piston compressors, which are known to be less efficient.

As discussed by Dmitriev and Arbon in detail in [4], the conical screw compressor does not have the "blow hole" and therefore can reach effective sealing between compression chambers even with water. This paper presents results of the most recent work: a 2kW model of the conical compressor (codenamed VERT.80) with water-injection demonstrated a 34% better energy efficiency than a scroll compressor of a similar capacity. The conical screw package drew 13% more power from the mains supply and produced 42% more flow. The size of the conical screw package is 46% of that of the scroll package. This new machine can be a promising solution, especially when serving as a local source of oil-free air.

2. About the conical screw compressor

The conical screw compressor is a modification of the screw compressor, which is different from the well-known twin-screw type. In the twin-screw compressor the helical rotors run on parallel axes enclosed in the casing; N Stošic writes that two such rotors effectively form a helical gear [5]. In the conical screw compressor, the male rotor is enclosed in the female screw rotor, they revolve on eccentric axes and form a cycloidal gear [4], see Fig.1.

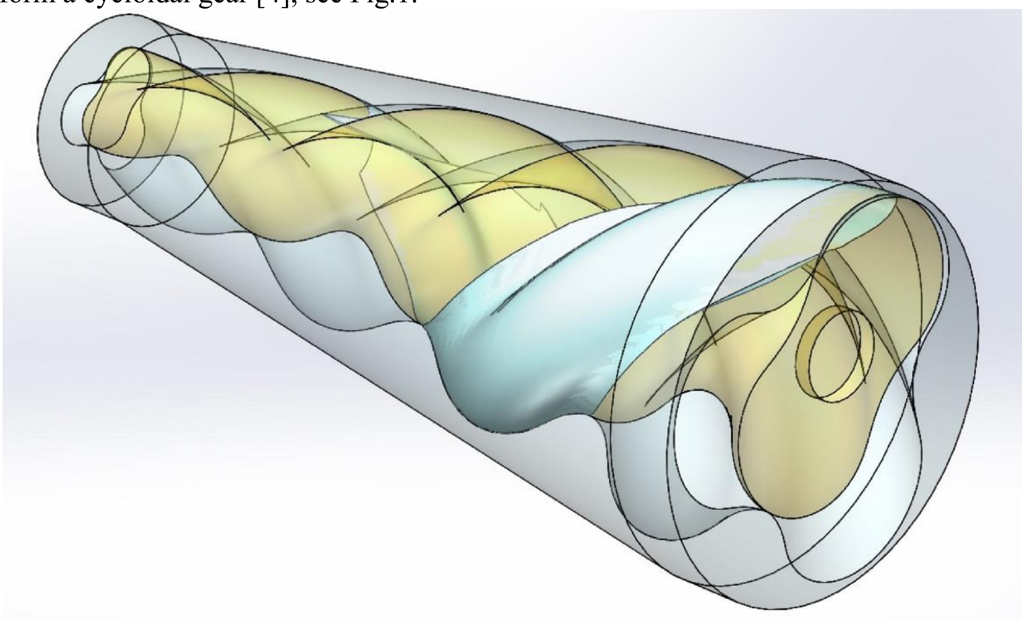

Figure 1. The male, epicycloidal (yellow) and the female, hypocycloidal (light grey) conical screws. Compression chamber is highlighted in light blue.

The concept of the conical screw compressor was first described by Chang of Robbins & Myers, Inc., USA in 1956 [6]. Manufacturing of this compressor required mathematical modelling, computer-aided design (CAD) and manufacturing methods which were beyond the reach at the time. Such methods were developed by Dmitriev and Tabota at Vert Rotors UK Ltd, UK, and in 2014 the first working model of a conical screw compressor was presented at 12th European Fluid Machinery Congress in 2014 [7]. The conical compressor was developed further, and a miniature modification was presented by O.Dmitriev, Tabota and Arbon at 9th Conference on Compressors and their Systems in 2015 [8].The model presented in 2014 operated with oil injection. In 2016, at the 13th European Fluid Machinery Congress, Dmitriev and Arbon presented a 2kW conical screw compressor with water-injection [4].

Figure 2.Bare-shaft conical screw compressor VERT.80

The conical compressor consists of two conical screw rotors. The male epicycloidal rotor is positioned inside the female hypocycloidal rotor. At each planar cross-section they create a cycloidal gear. The rotors revolve on fixed offset axes.

At suction, a volume of air enters the compression chamber at the large end of the cone. When the rotors revolve, the chamber is isolated and the air is trapped inside the closed volume. Following the rotation of the rotors, this closed volume is propelled towards the small end of the cone. The diameter of the compression chamber reduces progressively, the volume decreases and the pressure increases. High-pressure gas is discharged from the small end of the cone.

The authors have been working on evaluating efficiency of oil-free operation of the conical screw compressor with water injection, in comparison with other oil-free compressors.

3. Test of the 2kW conical screw compressor

3.1. Test setup

The conical screw compressor package is built with the bare-shaft compressor element, as shown in Fig.3 below.

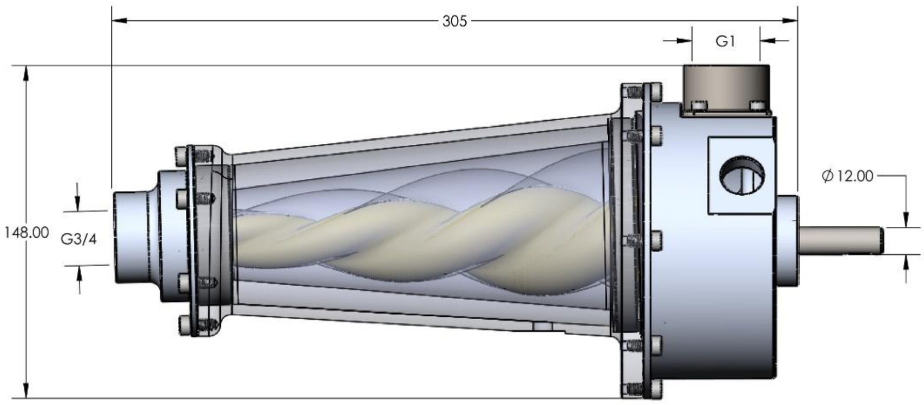

Figure 3.Dimensional drawing of the bare-shaft conical screw compressor VERT.80

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Two oil-free, floor-mounted compressor packages of similar capacity were compared: a 2kW water-injected conical screw compressor, VERT.80, and a 1.5kW scroll compressor, Atlas Copco SF 1, see Fig.4.

Figure 4.Scroll compressor Atlas Copco SF 1 (left) and conical screw compressor VERT.80 (right)

The discharge pressure of both compressors was set with a pressure relief valve, Norgren V74G-4GK-NMN, connected to the discharge port of the package. When the pressure relief valve connected to the scroll compressor was loaded to 8 bar(g), the compressor switched off automatically. Because of this, the scroll compressor was characterised at 7.5 bar(g) load.

The test measured the actual electric power drawn by the compressor assembly from the mains supply, instead of nominal shaft power. The power was measured with Digital Power Meter ABB C13 LCD.

Flow rate was measured with air flow meter SMC PFMB7501-F04- E (rated flow rate 1 to 500 l/min).

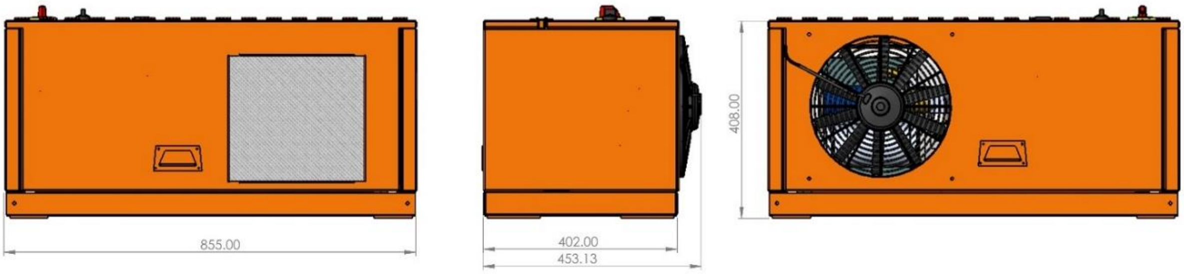

Figure 5. Dimensions of the conical screw compressor VERT.80

Table 1. Evaluated compressor packages

Compressor Package Designation	Working element	Dimensions	Weight	Type of operation	Motor speed r/min	Rated motor power
SF 1	Scroll	590x600x850 mm	120kg	Dry-running	2885	1.5kW
VERT.80	Conical screw	855x402x408 mm	90kg	Water injected	2920	2kW

3.2. Test results
The conical screw compressor was loaded to 8 bar(g), and performed at specific power of 13kW/m^3/min. The scroll compressor was loaded to 7.5 bar(g) (because at 8 bar(g) it switches off automatically), and operated at specific power of 19.7kW/m^3/min. In this comparison the conical compressor demonstrated 34% better energy efficiency.

The size of the conical screw compressor package (as shown on Figure 5) is 855 x 402 x 408 mm (0.14m^3 volume), and weight is 90kg. The size of the scroll compressor package was 590 x 600 x 850 mm (0.3m^3 volume) and weight was 120kg[2]. This comparison shows that the volume occupied by the conical screw compressor package is 46% of the volume of the scroll package, and weight of the conical screw package is 25% less than the scroll package.

As a third comparison, the flow rate and power of both compressors were analysed. According to the brochure for the scroll compressor, the flow rate was 2.9 l/s, or 174 l/min, installed motor power was 1.5kW, and maximum pressure was either 8 bar(g) or 10 bar(g). The scroll compressor was loaded to 7.5 bar(g) by setting a pressure relief valve, and measurements showed the following:
(A) the flow rate at 7.5 bar(g) was 127 l/min. The observed flow rate was lower than specified in the brochure, and it was understood that the brochure provided information for an unloaded compressor.
(B) the power drawn from the mains supply was 2.5kW. It was understood that the power of 1.5kW described in the brochure was for an unloaded compressor, possibly excluding the electric consumption of other components of the package.

The conical screw compressor was loaded to 8 bar(g) by setting the pressure relief valve, and the following observations were made:
(A) the air flow rate was 220 l/min;
(B) the actual power drawn from the mains supply was 2.86kW.
It should be noted that the water flow rate (in the closed loop system) was 13-15 l/min.

It can be concluded from the third test that the conical screw compressor used 13% more power than the scroll compressor. The power consumption of both compressor packages is in reasonably close proximity to each other. The flow rate of the conical screw machine was 42% greater than one of the scroll machine.

Summary of the test data is shown in the Table 2 below.

Table 2. Test results

Compressor package	Pressure load	Flow rate	Power consumption	Specific power
SF 1	7.5 bar(g)	127 l/min	2.5kW	19.7 kW/m3/min
VERT.80	8 bar(g)	220 l/min	2.86kW	13 kW/m3/min

3.3. Conclusions of the test
It can be concluded that tests of the water-injected compressor VERT.80 follow the theoretical assumption that water-injected compressors are more energy efficient than adiabatic compressors.

[2] Dimensions were measured, weight was taken from atlascopco.com

The test demonstrated that conical screw compressors are capable of meeting the market requirements for portable oil-free compressors sub-15kW.

The dimensions and volume of the conical screw compressor package were dramatically smaller than ones of the scroll package, which may be beneficial for certain applications. Examples of such applications include breathable air systems in oil & gas offshore platforms where size is highly important.

3.4. Discussion and further work
TheVERT.80 tested is currently development package, and it includes several non-optimised parts. Because of this, the authors are working to change non-optimal components, before the assembly is ready for serial production. For example, many components of the bare-shaft compressor assembly were produced from 316 stainless steel. The casing and primary separator were produced from extruded aluminium, and some other parts from brass. As such, this combination of materials, in contact with water, induces galvanic corrosion, with oxides clogging filters very quickly. Further development work will include anodising aluminium parts, and replacing brass with stainless steel.

Further, integrating the primary separator with water filter and water mist separator can help to replace tubes and fittings, and reduce the size of the package even further.

4. 8 bar(g) pressure achieved with the miniature 40W screw compressor

4.1. Results of production and testing
Further work was undertaken to miniaturise the conical compressor and see a practical limit of the screw compressor technology. A new compressor assembly with 40mm-long male and female conical screws was designed and manufactured. Swept volume of this compressor was 0.4 cc. A drawing of this miniature screw compressor codenamed VERT.04 is shown in Fig.6 below.

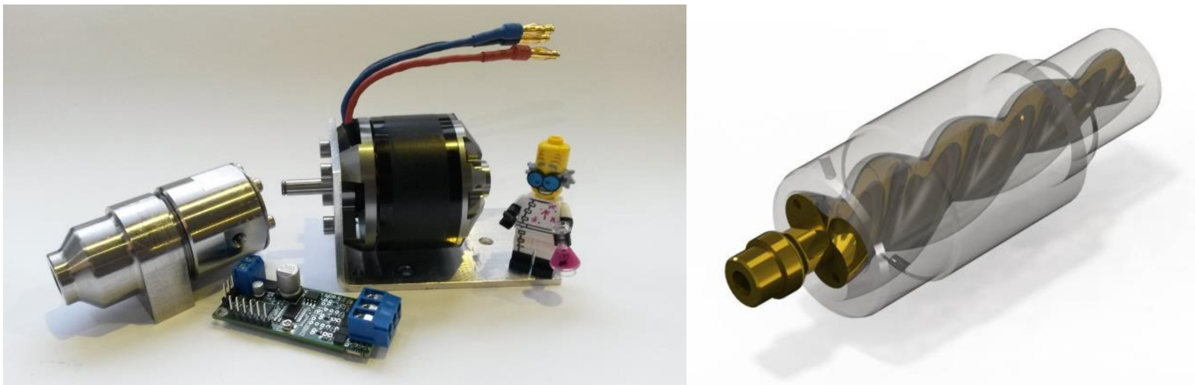

Figure 6. Miniature conical screw compressor VERT.04

The machine recorded a power consumption of 36-40W (24V outrunner brushless DC motor, current 1.5A).

A water injected package was developed, which included three modular blocks: (a) a module with the bare-shaft conical screw compressor and motor, (b) a module with electrical components and heat exchanger, (c) a primary water separator also working as a pressure vessel, see Fig.7

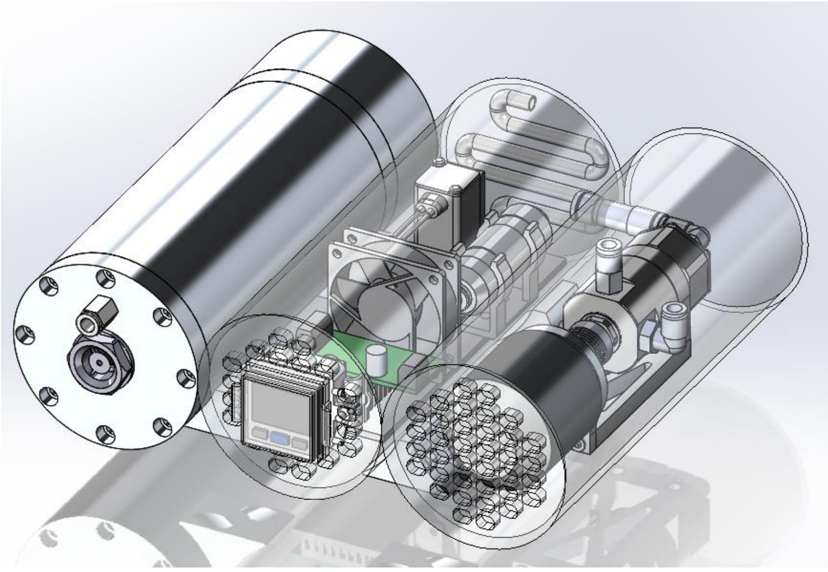

Figure 7. CAD view of the conical screw compressor VERT.04: Water separator / pressure vessel (left), module with heat exchanger and electronics (centre), module with compressor (right)

Working with water=injection, the miniature compressor VERT.04 produced a maximum discharge pressure of 8 bar(g) (or 115 psi(g)).

Figure 8. Test results showing 115.2 psi(g) / 8 bar(g)

4.2. Conclusions and discussion

The miniature VERT.04 is a working prototype and will be developed further before it is ready for the market.

The tests demonstrated that it the conical screw compressor is the smallest known rotary compressor that can achieve pressures such as 8 bar(g), with very low vibration and noise, which is very beneficial for medical or laboratory applications with sensitive equipment.

The pressure of 8 bar(g) demonstrated by the VERT.04 is considerably higher than pressures produced by other known miniature rotary compressors (1-1.5 bar(g) for rotary vane machines). While dry-running reciprocating piston compressors are capable of achieving pressures of 8 bar(g), they generate significant vibrations. Also, the thermodynamics of adiabatic compression dictate that the temperature of such machines escalates rapidly. The benefit of achieving pressures such as 8 bar(g) with water-injection is low temperature of the package, which supports much longer duty cycles

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