Scroll airmotor properties in comparison with piston and vane analogue

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Abstract. The experimental results of testing scroll machine in air motor mode, such as mechanical and flow performance; leakage coefficient; specific volume and weight power are presented. These results analyzed and compared with the same properties of radial – piston and vane air motors with equal power.

1. Introduction

Nowadays the scroll machines have been widely used as air or refrigeration compressors and also vacuum pumps. As compared with piston compressors, scroll compressors with the same capacity, have more energy efficiency (about 10-15 %), smaller dimension and weight (accordingly 25-40 % and 15-20 %), a low level of noise and vibrations. Now the actuator power range of scroll compressors is from few tens Watts [1] to tens kWts (Emerson ZP725K from “Copeland”). The volumetric rotary scroll machine is reversible and can function in air motor (expander) mode without any significant constructive modification and with preservation all advantages to piston air motors.

Today, quite a large number of works have been performed on using a scroll machine as a gas motor for various applications, especially for low-grade heat utilization systems based on Organic Rankine Cycle [2]. The “Air Squared Manufacturing”(USA) products specially designed scroll gas motors (working medium freon) for driving the generator in waste heat recovery systems [3]. Another application of scroll machine is associated with the creation of compressed air energy storage in solar and wind power stations [4, 5], as well as emergency power systems [6]. In [7] a scroll machine for energy storage system with two moving scrolls connected by synchronizing device is considered. This makes it possible to work in the compressor and motor modes. Increasing the energy efficiency of scroll air motor, by placing inside the scrolls insertions from rare earth magnets, is devoted to [8].

The investigation of the scroll machine in air motor mode began quite a long time ago [9,10]. But at the present time, in technical literature there are no data allowing to comparing the

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characteristics of scroll air motor with the corresponding indices of the other types of air motors commercially produced by industry [11]. These data are usually given in the catalogues of manufacturers in the form of mechanical and air consumption characteristics, weight and dimensions. The most interesting is the comparison with the characteristics of such mass-produced types of air motors as vane (up to 75 – 80% of the market of air motors) and radial piston. Carrying out such a comparative analysis is the purpose of this paper.

Figure 1. Appearance and mutual position of scrolls: a) fixed scroll, b) movable scroll, c), d) – two positions of the movable scroll with the angles of rotation of the output shaft differing by an angle of 180°. 1 — outlet port, 2 — housing, 3 — fixed scroll, 4 — movable scroll

2. Test rig and experimental results
As a scroll air motor was used the converted compressor “Mitsubishi” model MSC90CAS from car air conditioner. In Fig.1a, b show a fixed and movable scrolls respectively. As a counter-rotating device of moving scroll use the Oldheim coupling. In Fig.1c,d show the two positions of the movable scroll with the angles of rotation of the output shaft differing by an angle of 180°.

Figure 2. Test rig. 1 — scroll airmotor, 2 — bellows coupling, 3 — powder electromagnetic clutch, 4 — torque sensor.

Figure 3. Mechanical and air consumption characteristics of scroll airmotor at 0,6 MPa. 1 — developed moment, 2 — power, 3 — specific flow consumption

To measure the mechanical and flow consumption characteristics of scroll air motor a test rig was assembled, part of which is shown in Fig.2. In the compressed air preparation system a lubricator is installed to supply 5-7 mg/m³ of oil having a reduced viscosity at low temperatures (up to -25°C). The loading moment was created by an electromagnetic powder clutch P12S (Poland), whose shaft was connected through a bellows coupling with a scroll air motor shaft. The clutch housing (stator) is connected to the shaft of the static torque sensor YDNF-100KC
The steady angular velocity $\omega$ of scroll air motor shaft was measured by a laser tachometer “testo 460” (Germany). The compressed air flow consumption was measured at the air motor output using a “testo 6446” flowmeter, which was installed after the oil separator. The passage sections of the oil separator and the flowmeter were more than 5 times larger than the section of the exhaust port of air motor, which virtually eliminated the appearance of additional resistance on the exhaust.

Fig. 3 shows the mechanical and flow consumption characteristics of scroll air motor dependence of the steady state ($\omega$ – const): moment, power and specific flow consumption at supply pressure $p_m = 0.6$ MPa. Here, the specific flow consumption pressed air, reduced to normal conditions is the consumption per unit of developed power. Mechanical and flow consumption characteristics for this scroll air motor at supply pressures of 0.5 and 0.3 MPa are given in [12]. Externally the curves in Fig. 3 look similar to the corresponding characteristics of other types of volumetric air motors. Pressure 0.6 or 0.63 MPa the most commonly used supply pressures, for which all characteristics are given in the catalogs of manufacturers. It should be noted that recalculation of experimental data given in [10] for scroll air motor with other parameters gives approximately the same value of specific flow consumption – 0.8 m³/min kW at developing power of 0.6 kW and $p_m = 0.41$ MPa.

To determine leakage coefficient (the relation of flow consumption at $\omega = 0$ to flow consumption at maximum power) measurements were carried out at the braked rotor for two positions of the movable scroll shown in Fig. 1c, d. For the position corresponding to Fig. 1c, depending on the supply pressure, the flow consumption varies practically linearly from 0.03 m³/min at $p_m = 0.1$ MPa to 0.16 m³/min at $p_m = 0.6$ MPa. At rotor position, as shown in Fig. 1d, the flow consumption is approximately 7 – 8% higher, which is explained by the decrease in pneumatic resistance formed by the tangential and radial gaps between the scrolls.

3. Comparison of characteristics with other types of air motors

It is necessary to compare the characteristics of different types of air motors with their approximately equal power developed at the same supply pressure because for air motors of one type, but different power, the specific characteristics may differ significantly. We have analyzed catalogs of more than ten leading world manufacturers – producers of piston and vane air motors. Some of these catalogs are given in [13–20]. For comparison, samples of air motors, which in our opinion have the best performance (except cost) were selected. So, among the vane air motors we take two models of “Atlas Copco”: model LZB54A180-11 with a large ratio of the stator length to its diameter, which allows to obtain good volumetric and weight specific power, and model “heavy series” LZL05S, with smaller ratio stator length to its diameter. More details about these air motors can be found in [15]. Among the piston air motors were selected models of radial piston RM110 from “Globe” and axial piston A6 series from “Gardner – Denver”.

Table 1 shows the main indicators of this air motors, as well as the performance of our scroll air motor. In Fig. 4 one graph shows the mechanical characteristics of the three types of air motors clearly illustrating their working areas.

First of all, pay attention to high energy efficiency of scroll air motor. This is due to the following factors.

Leakage effects. For radial — piston air motors the main leakage occurs in a rotating distributor of compressed air. A small part of the compressed air from the supply line can fall right on the exhaust. For vane air motors tangential end leakage can lead to similar processes and significantly reduce energy efficiency. In scroll air motor the tangential and radial leakages from central chamber pass other chambers before come to atmosphere and take part in forming moving torque.

Harmful (or “dead”) volume. Radial — piston air motor has a harmful volume in the form of channels connecting the rotating distributor with the working chambers. Moreover, these
Table 1. Main indicators of air motors and scroll air motor

| Model                  | Power $kW$ | Supply pressure $MPa$ | Specific flow rate $m^3/min$ $kW$ | Specific weight power $kW/kg$ | Specific volume power $kW/l^3$ | Leakage coefficient |
|------------------------|------------|-----------------------|-----------------------------------|--------------------------------|---------------------------------|---------------------|
| Atlas Copco LZB54A180  | 1.2        | 0.63                  | 1.13                              | 0.51                           | 2.12                            | 0.22                |
| Atlas Copco LZL05S     | 1.3        | 0.63                  | 1.7                               | 0.33                           | 2.2                             | 0.2                 |
| Globe RM-110           | 1.15       | 0.60                  | 1.3                               | 0.09                           | 0.46                            | 0.12                |
| Gardner-Denver A6 series | 1.42   | 0.62                  | 1.24                              | 0.12                           | 0.45                            | –                   |
| Scroll airmotor        | 1.25       | 0.6                   | 0.78                              | 0.29                           | 0.94                            | 0.16                |

Figure 4. Mechanical characteristics: 1 — radial-piston airmotor RM110, 2 — scroll airmotor, 3 — vane airmotor LZB54A180

channels are used both for filling the working chambers with compressed air, and for emptying. This results in an unproductive consumption a portion of the compressed air. Therefore, radial - piston air motor have a “soft” torque characteristic (see Fig. 4), which indirectly makes it possible to judge about the perfection of the organization the processes of intake and exhaust the compressed air in the working chambers. Scroll and vane air motors have practically no harmful volume, and this is one of the reasons why they have more “hard” torque characteristics.
Built-in volume ratio. This indicator characterizes the ratio of the maximum to the minimum volume of the working chamber, when it is not communicating with the supply line and the atmosphere, and positive mechanical work is done only at the expansion of the compressed air in the chamber. Vane air motors are characterized by a small value of the built-in volume ratio – no more than 1.4 (for non-reversible models). For reversible models, this indicator is smaller. For piston air motors, the built-in volume ratio can reach 7-8, but in practice it is somewhat lower. The scroll air motor represented here has a built-in volume ratio of 2.95. This value was determined on the basis of the relationships for calculating the volumes of the scroll air motor chambers, given in [21]. Together, these factors provide high energy efficiency to scroll air motor.

An important operational indicator of air motor functioning quality is the noise level accompanying its operation. The noise effect consists of two components: from mechanical interaction of moving parts and pulsations of compressed air on the exhaust. In [22], noise data are reported for a 0.36 kW vane air motor (Atlas Copco), where, without a muffler on the exhaust, it is 94 dB, and with a muffler of 77 dB. For radial – piston P1V-P series of the company "Parker Pneumatic" with a power of up to 0.5 kW at idle, the noise level without a muffler is 95-100 dB, and with a muffler 75 – 80 dB at a supply pressure of 0.5 MPa. For a scroll air motor with a power of 10 kW [6], the noise level at a distance of 5 meters is less than 65 dB, and in [3] a 1 kW scroll motor in freon is 55 dB. As can be seen from the data presented, and according to this index, the scroll air motor has significant advantages over piston and vane air motors.

4. Concluding Remarks

From the characteristics of the scroll air motor considered here, it can be concluded that the latter is not inferior in most indices, but in terms of specific consumption it surpasses traditional piston and vane air motors of comparable power.

However, the list of characteristics considered here is not complete. In the future, it is necessary to determine such characteristics as the starting torque (its magnitude as a function of the initial angular position of the movable scroll), the effect of radial loads on the output shaft, the minimum stable revolutions, and the relative cost. These data will allow us to more reasonably judge the competitiveness of scroll air motor. It is necessary to compare the characteristics of different types of air motors with their approximately.

It should be noted that at a cost of pneumatic energy (the main line with $p_m = 0.8 – 1$ MPa) is 5 to 6 times higher than electricity, the energy efficiency index may in some cases be decisive. Also, the energy efficiency of air motors is important for autonomous systems with a tank power source, because this directly affects the working time of the system. In view of the foregoing, we can expect a wider use of scroll air motors in various applications where piston or vane air motors were previously used.

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