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ABSTRACT

Rotating vacuum pumps used in various fields have been required to have high performance, compactness, low noise/vibration. Although, a sliding vane type has been popular as a rotary vacuum pump, the authors paid attention to the possibility of a scroll vacuum pump satisfying these requirements.

Scroll machines have very good characteristics, i.e. low noise/vibration, mechanical simplification, fewer parts as compared with sliding vane type machines. The authors have attemped to develop a scroll vacuum pump.

A rotating mechanism was employed instead of an orbiting mechanism from the point of view of load pattern and very good sealing characteristics. Adopting the rotating mechanism, the radial sealing mechanism is particularly easy and effective due to the stationary seal line. A spiral with zero top clearance volume and a compact Oldham coupling were adopted. An ultimate vacuum pressure of 1×10^{-4} Torr for oil flooded operation was achieved at 1800 rpm.

This paper describes the authors design philosophy concerning the scroll shape, Oldham coupling, and oil sealing mechanism. Also, the experimental results are presented.

INTRODUCTION

Vacuum pumps have been used in various fields, semi-conductor device, new advanced materials, nuclear fusion, etc. Recently, due to the extensive applications in these fields, vacuum pumps have been required to meet various demands.

An oil-sealed rotary vacuum pump is a most typical one used in the pressure range above medium vacuum, and high performance, compact size, easy maintenance, low noise, and low vibration are required of it.

Whereas sliding vane rotary vacuum pumps are widely used today, the authors have attempted to develop a scroll vacuum pump to respond to the above demands.

The scroll machines have two types. One is an orbiting type with one scroll fixed and the other orbiting against it. The other type is a rotating type with two scrolls rotating in the same direction as each other.

An orbiting type has already been developed as a refrigeration compressor in air conditioning equipment. Only one orbiting type is seen as the vacuum pump in reference[(1),(2)], the rotating type scroll vacuum pump which has been described here is the world's first.

The scroll machines have such attractive features as : good sealing characteristics, low vibration and noise, mechanical simplicity, fewer parts, and so on. And the sealing technique in the rotating scroll type is easier than in the orbiting type.

We conducted a basic study of the rotating scroll vacuum pump with the above features. The results of the study of the model which has 200(ℓ/min) in the speed of exhaust are reported in this paper.

ROTATING SCROLL MECHANISM

Principle Of Compression

The compression process is shown in Fig.1. Two identical scrolls, whose axes of rotation do not meet each other, are assembled at a relative angle of the 180°, so that they touch at several points and form a series of crescent-shaped pockets. One of the scroll members, the driving scroll, is rotated directly by the motor, and the other, the driven scroll, is also rotated in the same direction by the oldham coupling mechanism maintaining the relative angle between the two scroll members. The suction port of the pump is at the periphery of the scrolls. As the two scrolls rotate counterclockwise, gas is trapped in a pair of pockets, and compressed by volume reduction while moving toward the center of the spiral. The compressed gas is exhausted through the discharge port at the center of the driving scroll. Since a new pair of compression pockets are formed with every scroll rotation, the same process goes on in sequence with the preceding process.

Features

The rotating scroll type has a number of useful features compared with the sliding vane type and with the orbiting scroll type. These include:

(1) The sliding vane rotary vacuum pump is constructed by the rotor, casing, and two sliding vanes which are pushed out by the spring. (shown in Fig.2)
The main leakage paths in the sliding vane type are shown Fig.3. They are the clearances of the vane tips, and vane side, and the clearance between the rotor and the casing wall. Especially, the latter is the path connecting the discharge chamber to the suction chamber directly, with large differential pressure, thus allowing gas to leak easily.

On the other hand, in the scroll type, the leakage paths are the clearances between the flanks of the wraps (radial clearance) and between the tip of the wrap and the end plate (axial clearance). There is no leakage path connecting the discharge and the suction chamber, as shown in Fig.3. It is easier to seal the gas in the scroll type than in the sliding vane type, because of this multistage sealing mechanism.

(2) The rubbing speed between two scrolls in the scroll type is one seventh lower than that between the tip of vane and the cylinder wall in the sliding vane type. A low rubbing speed is of benefit for the machine's durability.

(3) In the scroll type, the compression process is performed slowly and two to three compression processes go on simultaneously. Additionally, the compression chambers are symmetrical with respect to the rotating axes. This results in a smooth operation and little fluctuation in the driving torque and the gas pressure load, and thus vibration and noise are reduced.

(4) The position and the direction of seals between the flanks of the wraps rotate around the rotating axis in the orbiting scroll type. On the other hand, as shown in Fig.1, in the rotating scroll type, the positions of the seal line are formed into a line, and the direction of the seal is not changed.[3] Thus, the radial clearance of the rotating scroll type easily sealed by adjusting the external force added to the driven scroll in the radial direction.

STRUCTURE

Although the rotary vacuum pumps perform the same function as the displacement type compressor, the operating conditions are considerably different from each other, for example, the rotary vacuum pumps have extremly high compression ratio, and no exhausting at an ultimate pressure.

Then, a sufficient performance can not be obtained with ordinary compressors. Therefore, technical improvements were made on many points of the high performance vacuum pump. The structure of the developed scroll vacuum pump and several improvements follow.

Arrangement

An overall structure of the rotating scroll vacuum pump with a volumetric flow rate of 200(ℓ/min) is shown in Fig.4. It is a vertical type vacuum pump. The drive motor is a 0.4kW, 4-pole induction motor located at the top of the case.

Compression elements, the driving scroll and the driven scroll, are located on the lower side of the casing. The Oldham coupling behind the driven scroll (shown in Fig.6) transmits the torque to the driven scroll, and maintains the relative angle of the two scrolls.

The gas is drawn into the vacuum chamber through the suction port, compressed and discharged to the exhaust chamber through the hole formed in the driving shaft, and finally exhausted to the atmosphere through the discharge port.

The sealing arrangement is provided at the point where the driving shaft passes through the frame member to maintain a seal between the discharge chamber and the vacuum chamber.

Structural Element

(1) Wrap shape

The ultimate pressure is one of the basic performances. It is achieved when the mass flow rates of the suction gas and leakage gas are in equilibrium. Since, the displacement volume is constant in this pump, it is significant to minimize leakage from the compression chamber.

In the final stage of the discharge process, the top clearance is jointed to the innermost chamber, and the residual gas re-expands. In order to reduce the top clearance volume, the innermost wrap is formed by a circular arc. Fig.5 shows that the inner side and the top of the innermost wrap are formed with circular arcs, and connected to the involute of the circle. Satatisfying the following equations, the two innermost wraps always contact each other, and the zero-top clearance appears at the end of the discharge process.[3]

$$Rs = a\left\{\alpha - \frac{\beta}{2} + \frac{1}{2(\pi-\beta)}\right\}$$

$$R\ell = a\left\{(\pi-\alpha) - \frac{\beta}{2} + \frac{1}{2(\pi-\beta)}\right\}$$

$$\ell = a\sqrt{\left\{\frac{\pi}{2} - \frac{\beta}{2} - \frac{1}{2(\pi-\beta)}\right\}^2 + 1}$$

$$\alpha = \frac{\pi}{2} - \beta - \tan^{-1}\left\{\frac{\pi}{2} - \frac{\beta}{2} - \frac{1}{2(\pi-\beta)}\right\}$$

where "a" is a radius of basic circle, "ℓ" is a distance between centers of two circles, R is a radius of circular arc, and α,β are angles respectively (see Fig.5).

Besides the zero-top clearance, by fitting the discharge valve to minimize the residual volume, the re-expanded gas was reduced, and the ultimate pressure performance was improved.

(2) Clearance seal

Mechanical sealing is available to seal the radial and axial clearance due to low relative speed between the two scrolls. A seal element of PTFE was inserted tightly in the groove on the top of the wrap. Adjusting the axial contact force to nearly zero, the axial clearance was minimized.

As described above, the position and the direction of the radial sealing are stationary in the space. Utilizing this, the radial sealing was achieved by adjusting the driven scroll in radial direction and, also, adding the radial contacting force.

(3) Oil circulation path

In the high vacuum condition, the mass flow rate is extremely small, so that the compressed gas is not exhausted through the discharge valve, and reexpands to the compression chamber. To solve this problem, oil was introduced into the innermost compression chamber from the oil resorvior through the hole in the driving shaft. Oil is discharged with the compression gas and continually replenished.

(4) Oldham coupling

The Oldham coupling for the rotating scroll type is shown in U.S.P.[4] However, being located at the periphery of the scrolls, the mass of this coupling is large, and the inertia force can not be ignored.

To make the Oldham coupling light weight, the authors adopted the unique structure, shown in Fig.6, placing the Oldham coupling behind the driven scroll.

As a results of this, the vibration caused by the inertia force was reduced.

EXPERIMENTAL RESULTS

Fig.7 shows the relation between the ultimate pressure and the diameter of the oil hole. It is seen that the ultimate pressure is influenced considerably by the introduced oil, and an adequate amount of oil keeps the ultimate pressure low.

The performance of the developed scroll vacuum pump with an oil hole of optimum diameter is shown in Fig.8, compared to the traditional sliding vane rotary vacuum pump. An extremely low ultimate pressure, 1×10^{-4}Torr, and a higher pumping speed at the pressure range around 10^{-4}Torr order were achieved.

Table 1 lists the specifications of the scroll vacuum pump compared with the sliding vane rotary vacuum pump. The maximum radial vibration, 30micron (p-p), was measured at the bottom flange. At the motor, it was about one-half. Noise was measured by the noise level meter, set at a point 1m away from the pump, and at a height of 0.25m from the floor. As a result, the noise level was about 60db-A.

As a result of structural imoprovements, even more compactness was achieved as much as a 12% lighter weight, and a 40% smaller setting area. Furthermore, the maintainability was obtained due to the simple structure and fewer parts.

CONCLUSION

The authors have attempted to develop a rotating scroll vacuum pump with attention to the features of scroll machines for a vacuum pump. The features of the developed vacuum pump are as follows.

(1) Low ultimate pressure is achieved by the adoption of a rotating mechanism in which radial sealing is easy, a spiral with zero top clearance, and an optimum oil injection.

(2) Low vibration and noise are given by small fluctuations of gas pressure load and torque, exact balancing of scroll and adoption of a light weight Oldham coupling.

(3) Excellent maintainability and compactness come from simple mechanism and fewer parts.
(4) The machine is constructed as the vertical type.

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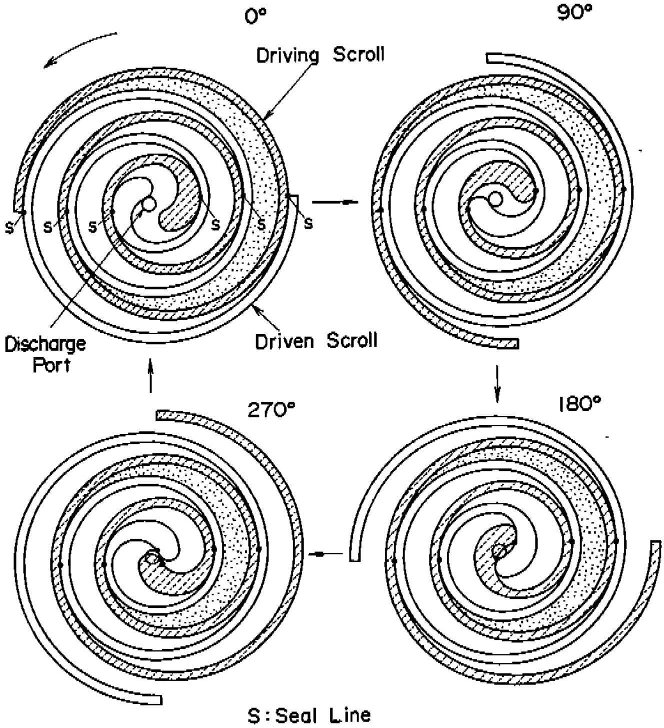

Fig.1 Principle of Compression

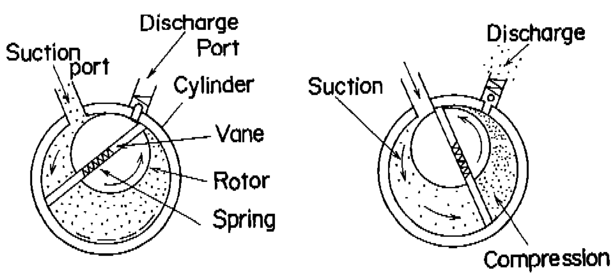

Fig.2 Sliding Vane Rotary Vacuum Pump

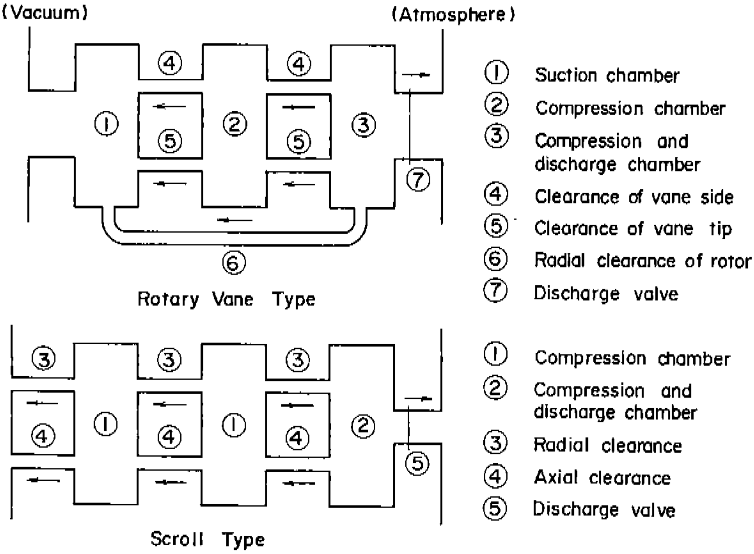

Fig.3 Leakage Path

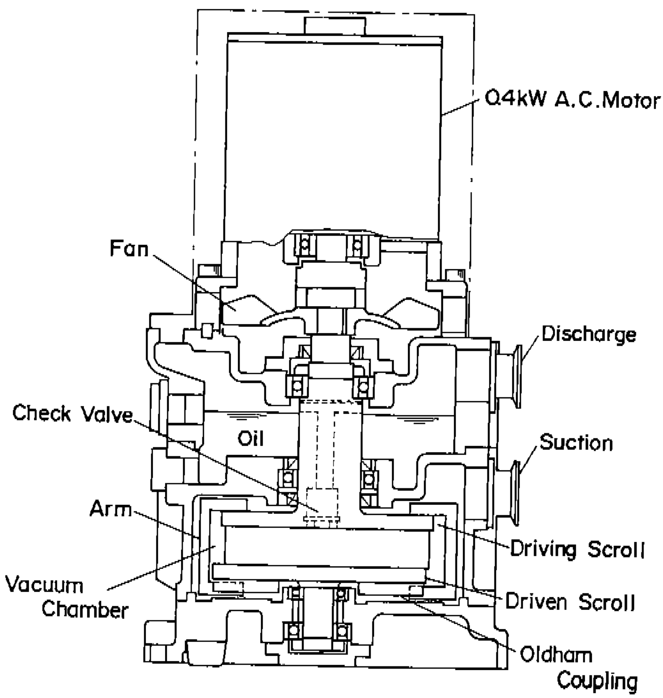

Fig.4 Strucure of Rotating Scroll Vacuum Pump

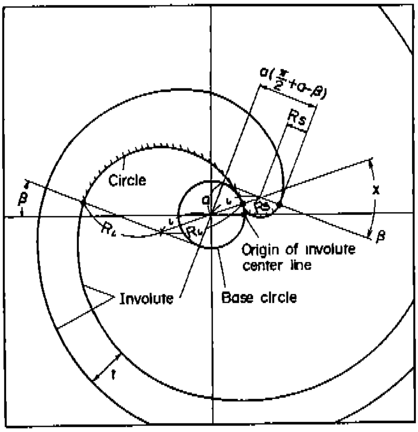

Fig.5 A Spiral with Zero Top Clearance

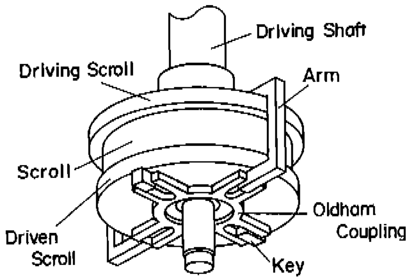

Fig.6 Oldham Coupling

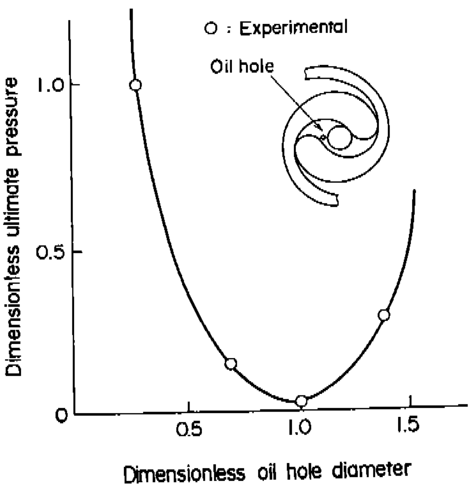

Fig.7 Relation between the Ultimate Pressure and the Diameter of the Oil Hole

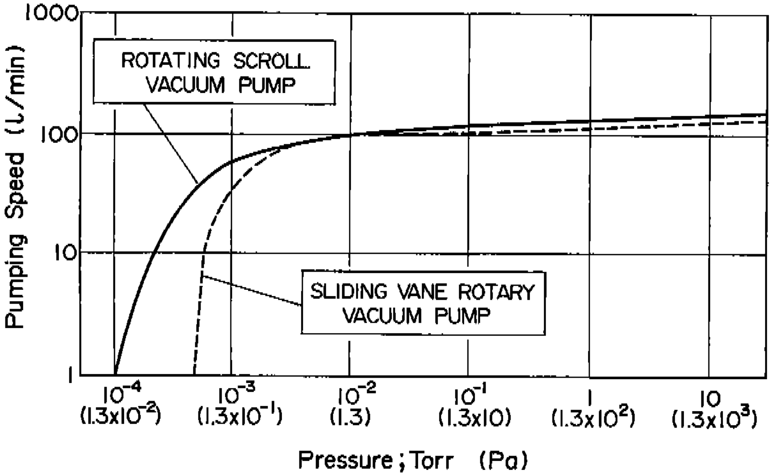

Fig.8 Peformance of the Rotating Scroll Vacuum Pump

Table 1 : Specifications of the scroll and the sliding vane rotary vacuum pumps

	ROTATING SCROLL VACUUM PUMP	SLIDING VANE ROTARY VACUUM PUMP
DISPLACEMENT (ℓ /MIN)	200	200
ULTIMATE PRESSURE (TORR)	1×10^{-4}	5×10^{-4}
VIBRATION LEVEL (MICRON, P-P)	30	60
NOISE LEVEL (dB-A)	60	60
NET WEIGHT (kg)	23	26
SETTING AREA (CM^2)	415	710
NUMBER OF PARTS	96	139