

FUNDAMENTAL DESIGN AND TEST OF NEW CONCEPT SINGLE-SHAFT DRY PUMP WITH FUNCTION OF TURBOMOLECULAR PUMP

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INTRODUCTION

The term “dry pump” is used to describe a positive displacement vacuum pump which discharges continuously to the atmosphere and in which the swept volume is free of lubricants or sealing fluids. One of the popular dry pumps is a multistage twin-shaft dry pump which works from atmospheric pressure to below 1 Pa. The first practical industrial dry pump was introduced in 1984 in Japan, which was based on the Roots principle with 6 stages in series. Then, the first of the Roots/claw machines was introduced as a 3-stage version in 1985. The 3-stage version was realized with a claw-type stages in series allowing operation at higher pressures up to atmospheric inlet pressure.[1] Fig. 1 shows a typical structure of Roots/claw dry pump. And since then, such types of dry pumps have been very familiar in the semiconductor industry. [2]

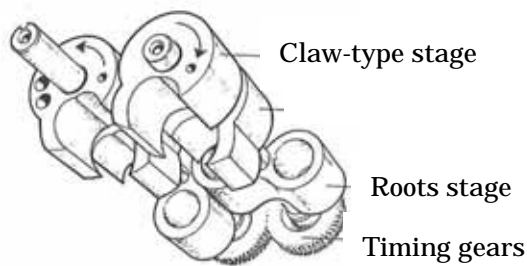


Fig. 1. Structure of Roots/claw dry pump [1]

On the other hand, a different type of dry pump was introduced in Japan in 1986 which is a single-shaft dry pump capable of operation from atmospheric pressure to 10^{-2} Pa. [3] Since then, such types of dry pumps were also launched in the semiconductor processing industry.[4][5] Fig. 2 shows a structure of a single-shaft dry pump IPX.[4]

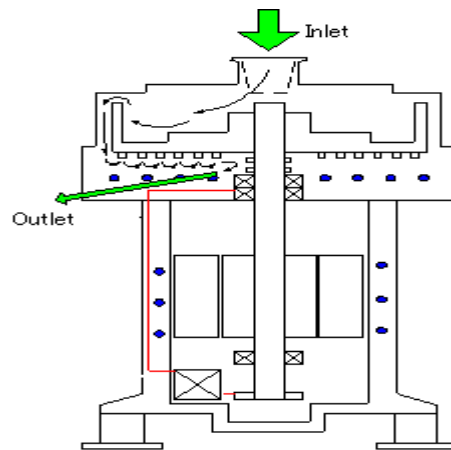


Fig. 2. Structure of BOC Edwards product IPX [4]

But, although single-shaft dry pumps are more compact and have lower ultimate pressure than conventional twin-shaft dry pumps, they have not been very popular in the semiconductor processing industry. This arises from the following drawbacks.

Firstly, they are best used only for clean processes and are not suitable for harsh semiconductor manufacturing processes because of the small gap between the rotor and stator and the high rotational speed of the rotor. Secondly, although the pumping speed at low pressure can be higher, the power consumption is higher at high pressure because of the high rotational speed of the rotor. However, this report shows the possibility of a new concept single-shaft dry pump which has high pumping speed as a turbo-molecular pump at low pressure, but relatively low power consumption at high pressure.

Concept of the new single-shaft dry pump

A turbine-blade rotor in a turbo-molecular pump is useful to achieve high pumping speed in molecular flow. But, it requires huge power to operate under continuum flow conditions. Consequently a pump that has both a dry pump function and a turbo-molecular pump function has not yet been realized.

The key point to realizing a pump that has high pumping speed as a turbo-molecular pump at low pressure, but relatively low power consumption at high pressure, is a torque-coupling mechanism between different rotor parts for the dry pump (molecular drag + fluid dynamic mechanism rotor) and the turbo-molecular pump (turbine-blade rotor).

It means that although the two rotor parts are fixed on the same shaft, only the dry pump part starts to rotate from atmospheric pressure, whilst the rotational speed of the turbo-molecular pump part gradually rises to the same speed of the dry

pump following decrease in pressure. Therefore, the need for high power consumption for the turbine blade is avoided. Fig. 3 shows a structure to realize this concept.

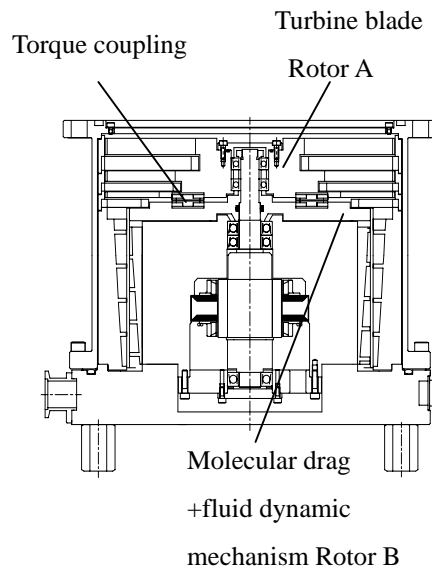


Fig. 3. Structure of the new single-shaft dry pump

Rotor B with a molecular drag stage and a fluid dynamic mechanism stage is rigidly fixed on the motor shaft. On the other hand, Rotor A with a turbine blade is fixed to rotate freely with a ball-bearing arrangement, and torque-coupled to Rotor B with a special coupling mechanism. Therefore, maximum power consumption comes from motor shaft with Rotor B and the force of the torque-coupling. The load presented by turbine-blade Rotor A is simply a result of the force transmitted by the coupling to Rotor B.

A prototype was developed to demonstrate the concept. The flange size is VG250 (250 mm in diameter), the height is about 330 mm, and the maximum rotational speed of the motor shaft is 26,000 rpm.

Characteristics of the torque coupling

Fig. 4 shows the rotational speed of both the turbo-molecular pump part (Rotor A) and the dry-pump part (Rotor B) at different pressures. Rotor B can rotate at nearly the same speed of the motor drive frequency in any vacuum pressure. On the other hand, Rotor A can not rotate at the same speed of the motor drive at high pressure. For example, when the motor-driver frequency is 3,000 rpm, Rotor B rotates at 3,000 rpm at any vacuum pressure, but Rotor A rotates at 3,000 rpm only at pressure lower than 900 Pa and more slowly at pressures above 900 Pa.

This means the following features.

Rotor B can rotate at the highest rotational speed limited by the maximum available motor power.

And depending on the inlet pressure, the rotational speed of Rotor A approaches the speed of Rotor B as the inlet pressure decreases. For example, in Fig. 4, the speed of Rotor A catches up to the speed of Rotor B at a pressure of 900 Pa.

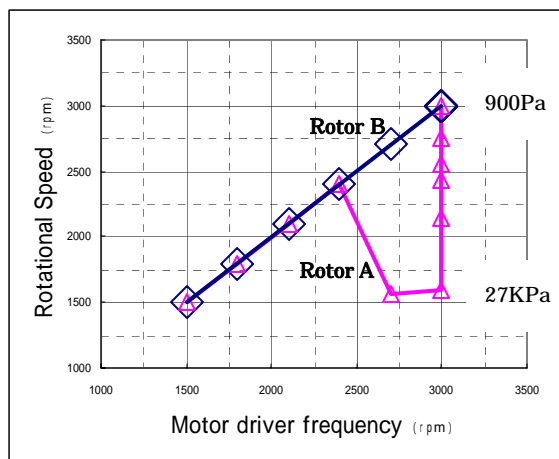


Fig. 4. Rotational speed of Rotor A and B in different pressures

Pump characteristics

A proto-type pump has been developed for a pumping speed of 1,000 – 2,000 l/s. The target design pumping speed of the pump is shown in Fig. 5. The pump developed is composed of 3 types of stages. One is a fluid-dynamic mechanism stage which is called “Regen one”. The second is a molecular-drag stage called “Holweck one”. The last is a turbine-blade stage called “Turbo-molecular one”

Each stage works well in a particular pressure range. “Regen one” works at pressures greater than 1,000 Pa. “Holweck one” works at pressures from 1 Pa to 10^3 Pa.

“Turbo-molecular one” works at pressures lower than 1 Pa.

The pump is expected to have a speed over 1,000 l/s at inlet pressures less than 10^{-3} Pa.

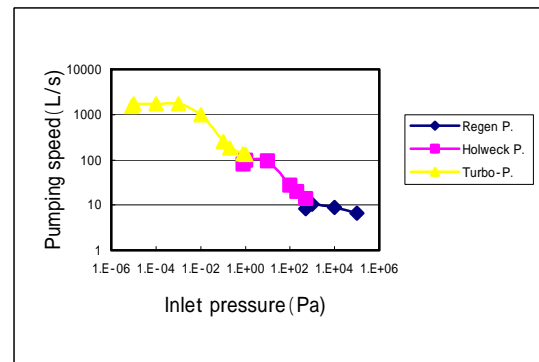


Fig. 5. Target design value of the pumping speed of the proto-type

When Rotor B with the Regen stage and the Holweck stage reaches a maximum rotational speed of 26,000 rpm from atmospheric pressure, our estimation of the motor power of Rotor B is a maximum of about 2 KW, peaking at speeds from 10,000 rpm to 12,000 rpm. Therefore, considering losses required for the bearings and

torque-coupling, we anticipate the proto-type pump will require 2.5 KW to operate.

Efforts are now on-going to verify the motor rating. Data acquisition on total pump performance is on-going as this paper is being written.

Summary

The pump described in this paper employs an innovative torque-coupling mechanism that provides pumping speeds similar to that of a turbo-molecular pump and a dry pump, but a power consumption similar to that of a dry pump alone.

References

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