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Evaluation of performance parameters of indigenously developed roots pumping system

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Abstract. Roots pumping systems are widely used in industries to generate vacuum with high pumping speed. In the present work, the performance parameters of indigenously developed Roots pumping system have been studied. The performance parameters being studied are the ultimate pressure, working temperature, compression ratio and pumping speed. Ultimate pressure of the Roots pump after continuous running of eight hours is found to be 1.1×10^{-3} mbar. The most important parameter of the roots pump is the zero-gas flow compression Ratio (K_o) which is found to be 18 for the pumping system under study. Efficiency of Roots pump is found to be 76% which is in good agreement as reported in the literature.

1. Introduction

Roots pumping systems have a wide range of applications. The roots pumping systems are very useful in evacuating large volumes in shorter periods of time due to very high pumping speed. This property make roots pumping systems, a preferable choice in coating and semi-conductor industry, chemical and process technology and research and development setups. Roots pumps, when combined with suitable backing pumps, make them adaptable for different applications.

The performance of the vacuum pumps can be evaluated from its ultimate pressure, operating temperature, compression ratio, pumping speed etc. In 1963, American Vacuum Society (AVS) issued tentative standard for measuring pumping speed of the vacuum pump, which was revised and published in 1971. In 1987, M. H. Hablanian recommended some practices for the pumping speed measurement of the vacuum pumps by incorporating newly established pumping methods and improvements in the high vacuum techniques. He explained the specifications of the experimental setups in detail [1]. B. R. F. Kendall recommended the procedures for measuring the pumping speed of the positive displacement mechanical vacuum pumps in 1989 [2]. In 1996, W. Jitschin*et.al.* measured the pumping speed of the rough vacuum pumps with stationary method and intermittent pump down method [3].

In the present work, the indigenously developed roots pumping system was tested. The roots pump is backed by a dual stage rotary pump. Its ultimate pressure and working temperatures are worked out for 7 hours of operation. The compression ratio and pumping speed of the roots pump is studied as a function of outlet pressure.

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2. Ultimate pressure and working temperature

The roots pumping system was tested for its ultimate pressure and working temperature before determining other performance parameters. The system was continuously operated for seven hours. The ultimate pressure of the roots pump was found to be 1.1×10^{-3} mbar with the maximum operating temperature of 37^{o}C.

3. Compression ratio

An important characteristic of the roots pump is the zero-load compression ratio K_o. It is the ratio of the pump outlet pressure to the pump inlet pressure [4].

$$K_0 = \frac{P_o}{P_i} \tag{1}$$

For roots pump, compression ratio is worked out without the admittance of gas flow to the pump inlet [5]. It is measured by the experimental setup shown in the Figure 1.

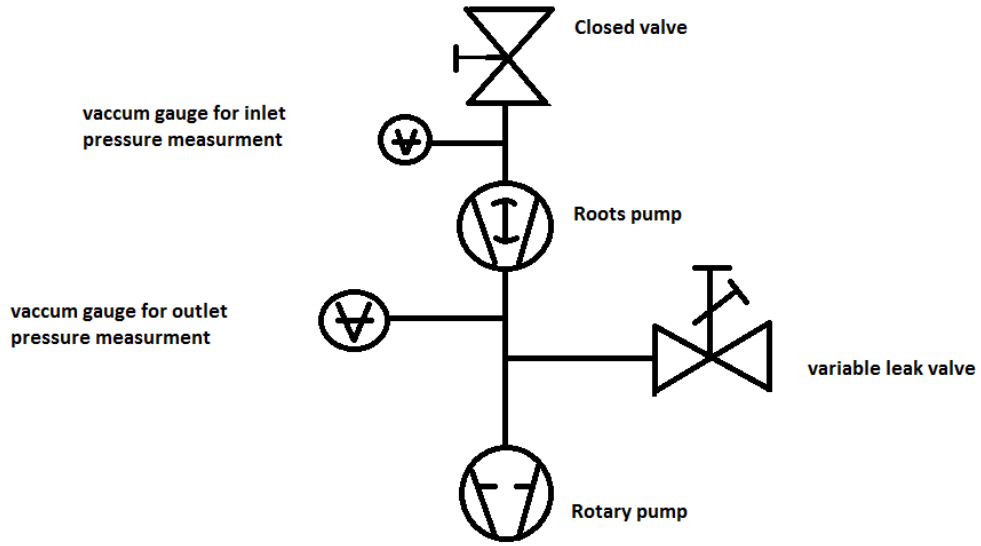


Figure 1. Experimental setup for determining compression ratio

The roots pump inlet is blanked off with a vacuum gauge and a rotary pump is attached to its outlet as backing pump. A low vacuum gauge is installed in the baking line to monitor the backing pressure of the roots pump. The air is admitted to the backing line via variable leak valve to adjust the backing pressure of the roots pump by throttling the rotary pump. This arrangement makes it possible to calculate the compression ratio over a wide range.

The observations were taken for the pressure range of 5×10^{-2} mbar to 118 mbar. This was done by the necessary throttling the rotary pump via the variable leak valve. The compression thus obtained, shown in Figure 2, has the conventional trend as reported in literature [6].

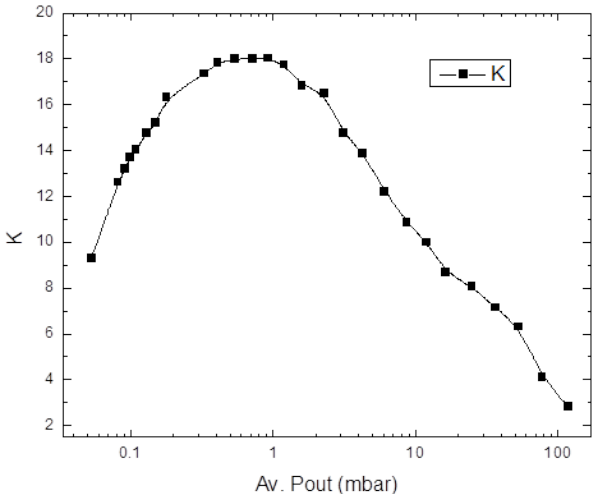


Figure 2. Behavior of compression ratio with outlet pressure

The maximum compression ratio of the roots pump is found to be 18 at the outlet pressure of 1 mbar. The compression ratio gradually decreases to about 3 upon the gradual increase of outlet pressure to 118mbar. Compression ratio also decreases to about 9 at the pressure of 5×10^{-2} mbar. The decrease of compression ratio values below 10 at 10 mbar and 10^{-2}mbar is due to the dominance of the back flow at higher pressure side and increase gas load due to desorption of gas molecules from rotors at lower pressure side [6].

4. Pumping speed

Pumping speed is the most important parameter of any vacuum pump. In ISO 1608/1, the pumping speed is defined as the volume of gas which flows through the pump inlet in unit time under ideal conditions. For experimental purposes, the volume rate of flow of a vacuum pump is taken to be the quotient of the throughput of that gas and the equilibrium pressure at a specified position in a test dome under specified conditions [7].

$$S = \frac{Q}{P} \tag{2}$$

The units most commonly used for the pumping speed are cubic meter per hour (m^3/h), liter per second (l/s) and cubic feet per minute (cfm).
The theoretical pumping speed of the roots pump is:

$$S_{th} = 4 \times n \times V' \tag{3}$$

Where n is the rotational speed of the rotors and V' is the volume of gas isolated from the inlet [8]. Therefore, at high rotational frequencies, high pumping speeds can be achieved with small roots pump. For the pump under study, the theoretical pumping speed is found to be 271m^3/h.
For the practical pumping speed of the roots pump at a particular backing pressure P_2 can be calculated by:

$$S = \frac{S_b S_{th} K_0}{S_{th} + S_b K_0} \tag{4}$$

Where, S_b is the pumping speed of the backing pump at the backing pressure P_2, S_{th} is the theoretical pumping speed of the roots pump and K_0 is the zero flow compression ratio of the roots pump at the backing pressure of P_2 [6].
The behavior of the pumping speed of the roots pump as a function of the outlet pressure is shown in Figure 3.

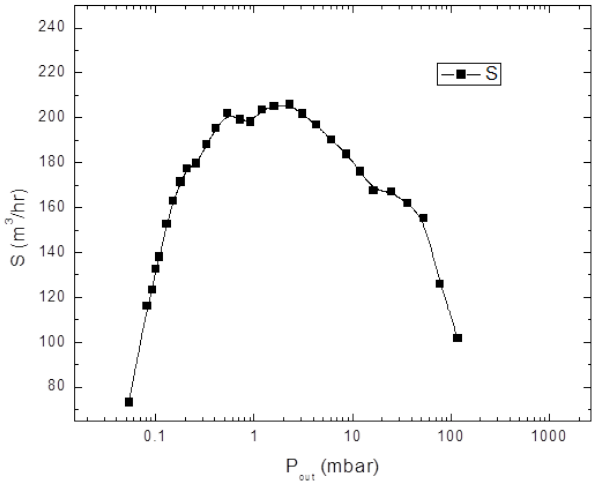


Figure 3. Behavior of pumping speed with outlet pressure

The maximum pumping speed of the roots pump is found to be 205m^3/hr at the outlet pressure of about 2 mbar. The pumping speed of the roots pump is found to be higher in the pressure range of 10^{-1} to 10 mbar. Beyond this pressure range, the pumping speed of the roots pump drops. The maximum efficiency of the roots pump is found to be 75% at 2mbar.

5. Effective pumping speed

The Effective Pumping Speed of the Roots pump is the product of Efficiency and theoretical pumping speed of Roots pump.

$$S_{eff}=\eta S_{th} \quad (5)$$

Where 'η' is Efficiency of Roots pump and $S_{th}$is theoretical pumping speed of Roots pump [5] . The Effective pumping speed is found to be 203m^3/h.

6. Gradation of pumping speed between fore pump and roots pump

There are two main aspects to determine the Gradation of the pumping speed from the Roots pump to the backing pump.

I. High volumetric efficiency required.
II. The maximum tolerable pressure difference of the Roots pump shall not be exceeded [8].

The Staging Ratio or Gradation of Roots pump is the ratio of actual pumping speed and pumping speed of backingpump. The staging ratio between roots pumping speed and backing pump is 1:5.7.

7. Max. pressure difference

Roots pump generate heat, when pumping gas at high pressure. Heat causes the rotors to expand; if unchecked, rotors expansion could destroy the pump. To avoid this heating effect, a maximum pressure difference between the inlet and outlet pressure of a Roots pump is specified.

$$\Delta P_{max}=P_{out}-P_i \quad (6)$$

for a short time without harm to the pump.[9]

8. The volumetric efficiency of roots pump

The formula for the Volumetric Efficiency of Roots pump is

$$E_v = \frac{K_o}{K_o + K_{th}} \quad (7)$$

Where K_0 is the zero flow compression ratio of the roots pump, K_{th} is ratio of theoretical pumping speed of Roots pump and pumping speed of backing pump [10]. The Volumetric Efficiency is found to be 75% which is good agreement with Mechanical Efficiency.

9. Conclusions

The performance of indigenously developed roots pumping system was tested at NINVAST in detail. Its ultimate pressure, operating temperature, compression ratio and pumping speed are some of the performance parameters being studied thoroughly. The roots pump with the ultimate pressure of 1.1×10^{-3} mbar, was found to be efficient in the outlet pressure range of 10^{-1}mbar to 1 mbar. It was found to be 75% efficient at the outlet pressure of 2mbar with 205m^3/hr pumping speed. Hence, it is found to be good to evacuate the system with high pumping speed.

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