7

Measurements of pump properties

7.1 INTRODUCTION

It is not our intention to provide in this chapter an exhaustive list of all international standard requirements in respect of measuring important pump properties, such as pumping speed, ultimate pressure and compression ratio [1]). The content is aimed at providing some degree of understanding concerning the methods by which pumping speed measurements and measurements of the compression ratio should be carried out, and gaining insight into the difficulties we can expect.

It is essential to all measurements to be discussed in this chapter that they are carried out under *operating conditions*. It is therefore necessary to let the pump in question warm up for at least a few hours. This ensures that the pressure gauge and its connection lead are pumped to a sufficient extent, the pump medium (in the event of presence) has come up to the required temperature and initial degassing effects (e.g. related to increased pump temperature) have passed.

7.2 MEASUREMENT OF ULTIMATE PRESSURE

The measurement of the ultimate pressure of a pump must, of course, be made with a pressure gauge, the measuring range of which extends to well below this ultimate value. According to current regulations, in a so-called *standard measurement*, the pressure gauge is to be mounted to a test volume whose diameter D should be at least equal to the pump inlet and whose height is 1½D. The gauge head must be connected at 1/3 of the height and may not protrude in the test volume. In addition, the method of gas admission in the test volume via a 90° upwardly bent capillary is accurately prescribed; see figure 7.1.

Depending on the pressure range, we can distinguish between ultimate pressures determined by the compression ratio of the pump and 'ultimate pressures' determined by desorption from the walls of the test volume. In the pressure range above about 10^{-1} Pa

[1]) For a complete list of the so-called Pneurop Regulations we refer to the publications of Machinenbau Verlag GmbH, Frankfurt, Germany.

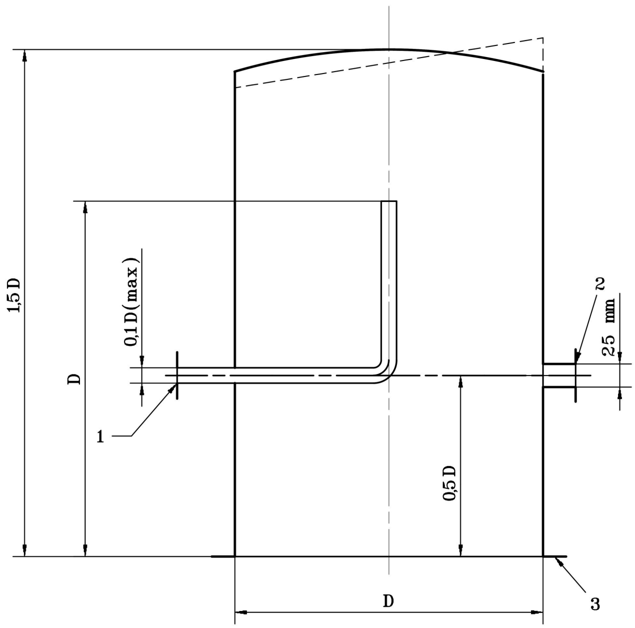

Figure 7.1
Simple test volume for ultimate pressure and pumping speed measurements. 1 - *connection for gas admission,* 2 - *connection for the pressure gauge,* 3 - *connection for the pump.*

(coarse and fine vacuum, see § 5.1) the contribution of the desorption to the prevailing pressure is negligible and we have to deal with an ultimate pressure of the first category, i.e. the achievable final pressure is determined by the quality of the considered pump. For pressures below 10^{-1} Pa, the influence of the desorption gas flow to the accessible ultimate pressure increases with decreasing pressure and we pass to 'ultimate pressures' of the second category. Under high and ultra-high vacuum conditions degassing of the walls usually leads to an equilibrium pressure which is significantly higher than *the intrinsic ultimate pressure* determined by the compression of the pump in question. To determine this intrinsic ultimate pressure, degassing must therefore first be made negligibly small. For this purpose, the system is very carefully cleaned prior to an ultimate pressure measurement and after evacuation baked at 300 °C for about 48 hours. The pressure as measured after cooling the test volume to room temperature is labelled by convention as the 'ultimate pressure' of the (ultra-)high vacuum pump. However, we note that this pressure is usually still an equilibrium pressure between pumping and degassing. Thus, basically we measure here a system property instead of a pump characteristic!

In the specifications of oil sealed rotary pumps as provided by the manufacturer the term 'ultimate pressure' usually refers to its value for permanent gases. Since the residual gas of such a pump in practice contains oil vapour and usually also water vapour, the actually attainable ultimate pressure is higher than the one indicated in the manufacturer's specification. By mounting a liquid nitrogen cooled trap between the pump and the pressure gauge, vapours are frozen and only the pressure of the permanent gases is measured.

7.3 PUMPING SPEED MEASURING PROCEDURES

The measurement of the pumping speed of a vacuum pump can be performed according to two basic principles, viz the *constant volume* method and the *constant pressure* method. Which of these two methods can or must be applied, depends on the magnitude of the pumping speed to be measured. Both methods are discussed for air. For other gases, the same procedure applies with the proviso that air must be replaced by the respective gas.

7.3.1 Constant volume method

In the constant volume method, the pump is connected to a vessel of known volume; see figure 7.2. The vessel should be well cleaned and dry and preferably have been pumped in advance. Furthermore, it quite generally holds that the pump must be brought at its operation temperature before commencing the procedure.

The measurement consists of registering the pressure drop in the vessel as a function of time after opening the valve to the pump. This can be done manually by using a stopwatch or automatically with the aid of a pressure gauge connected to a recorder or data processing system. The result is a $p(t)$-curve as schematically shown in figure 7.3. The pressure decays rapidly from an initial value (typically 1 atmosphere) and finally settles at a constant value p_u. During the measurement cycle the following applies at all times

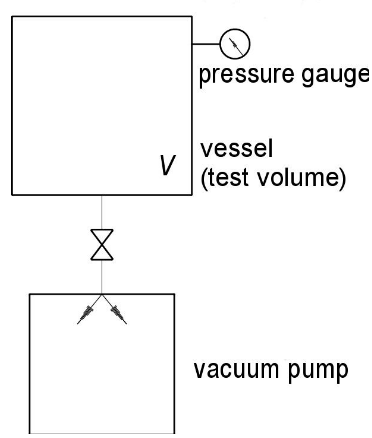

Figure 7.2
Set-up for measurement of the pumping speed according to the constant volume method.

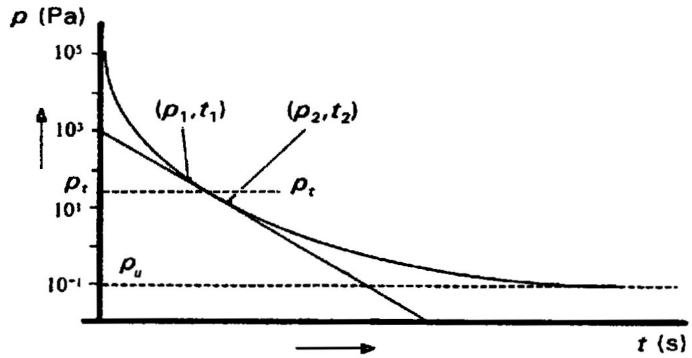

Figure 7.3
$p(t)$-curve obtained in a pumping speed measurement according to the constant volume method; the pumping speed at a certain pressure p_t equals the derivative dp/dt of the curve at p_t.

$$-V\frac{dp}{dt} = Sp \tag{7.1}$$

or

$$S = -\frac{V}{p}\frac{dp}{dt} \tag{7.2}$$

where V represents the volume of the vessel (m^3), S the pumping speed to the vessel (m^3/s) and p the pressure to the vessel (Pa).
At a certain pressure p_t the derivative dp/dt can be determined numerically by connecting in figure 7.3 two points (p_1,t_1) and (p_2,t_2) in the immediate vicinity at either side of the considered point p_t with each other by a straight line. For the slope of this line applies

$$\frac{p_2 - p_1}{t_2 - t_1} = \frac{\Delta p}{\Delta t} \approx \left[\frac{dp}{dt}\right]_{p_t} \tag{7.3}$$

Substitution of p_t and $[dp/dt]_{pt}$ in expression (7.2) provides the pumping speed at the pressure p_t. By applying this procedure to a number of points of the $p(t)$ curve, a pumping speed curve $S(p)$ is obtained.

For most vacuum pumps, the pumping speed remains constant over a wide pressure range and thus is pressure independent (see chapter 4). This constant pumping speed is usually indicated by S_0. From expression (7.2) it follows, that the curve $p(t)$ in this situation is purely exponential: