9

Sealing techniques and system components

9.1 INTRODUCTION

In general, a vacuum system is constructed from several components because of its usefulness for experiments or processes, control options in the system and ease of cleaning/modification. The connections between these components must be vacuum-tight, but in such a way that they remain demountable.
Where detachability is not necessary or even undesirable and a 'one-piece' assembly would be, in principle, more convenient, it is often advisable to opt for an assembly composed of several separate parts because of both manufacturing and economic reasons. These parts then need to be connected 'non demountable' together. Of course, for such permanent connections the requirement of vacuum tightness holds as well.

9.2 DEMOUNTABLE JOINTS

The demountable joints used in vacuum technology are not only flange connections between metal components. Tapered glass joints and glass-metal swivel joints, as for instance applied in chemistry, have also found use, but their application in vacuum systems in recent decades has greatly diminished. The advantage of simple design and corrosion resistance of glass has been outweighed by unsafety and fragility aspects. The availability of improved types of stainless steel and technological developments in metal-working have obviously contributed to this trend. We will therefore limit ourselves in this section to the treatment of the most commonly used connection type in today's vacuum technology: the *metal flange joint*.
With regard to the method of sealing metal surfaces, it should be noted that a flat and smooth surface still exhibits minor irregularities of a few microns. A rough calculation shows that a rectangular slit with a cross section of, for example, 1 cm x 30 *μ* and a length of 1 cm gives a leak rate for atmospheric air of about 0.1 Pam^3/s! This example shows that simply connected flat flanges do not yield a vacuum-tight seal just like that. Improvement could be obtained by firmly pressing the flanges to each other. Because of the flange

hardness, however, extremely large forces would be required in order to seal the connection slit. The solution for this is to bring a relatively soft material in between the two flanges, which fills up the unevenness without requiring large forces. To fill the irregularities the gasket material should be *plastic*, while in order to maintain the pressure exerted on the seat the material should be *elastic*. Unfortunately, there are no materials that possess both properties simultaneously to a sufficient extent. As a packing material usually an elastomer or a relatively soft metal is applied (see also chapter 10). Application of elastomers occurs because of their elasticity, Teflon and soft metals are used because of their plasticity.

9.2.1 Grooved flanges with elastomer sealing

For this sealing type, the seat for the elastomer gasket should be dimensioned such that in case of metal-to-metal contact of the flanges the gasket will receive the correct all-sided compression. To that end the following requirements must be met:

a. The cross section of the groove must be large enough to contain the sealing ring. As a rule, this means that the cross section of the groove should be about 5 - 10% larger than the cross section of the gasket. This is because of the incompressibility of the elastomer and the dead volume in the corners of the groove, that are not filled by the elastomer in pressing. In order to fill up these corners, a very large local deformation of the gasket would be required, making the elastomer lose its elastic properties.
b. In order to obtain a vacuum-tight seal, the compression of the sealing ring should be 20 - 40%, depending on the hardness of the elastomer. The ideal groove must give the same degree of distortion in each part of the cross section. Sharp corners in the groove will deform the gasket too much and should therefore be avoided.

Further practical requirements are:

c. The gasket should be positively retained in the groove during disassembly.
d. The gasket should be easily removable, without damaging the groove.
e. The 'dead' volume created at the vacuum side of the gasket must be adequately pumped via special orifices provided for this purpose between groove and vacuum system.
f. For reasons of gas release and permeability, the surface of the gasket exposed to the vacuum side should be minimal. This requirement is particularly important when the gaskets are used under high vacuum conditions.
g. The gasket should be able to be re-used many times. In this respect, over-compression of the gasket or grooves with sharp corners have to be prevented under all circumstances, since they lead to permanent deformation or 'cutting off' the gasket in the groove.

Some examples of screw and clamp connections are shown in the figures 9.1 and 9.2. The simplest one of these configurations is the combination of 'O-ring (sealing ring with a circular cross-section) + groove with rectangular cross section'. However, there is the drawback of the asymmetry in sizing of the two opposite flanges (also called "male-female" connection), which interferes with the interchangeability. The width A and depth B of the groove (see diagram in figure 9.3) are determined by:

1. the hardness of the elastomer;
2. the required compression $\kappa = 1 - B/d$ in relation to this hardness;
3. the volume factor f in relation to the permissible dead volume: $A \times B = f \times \frac{1}{4}\pi d^2$.

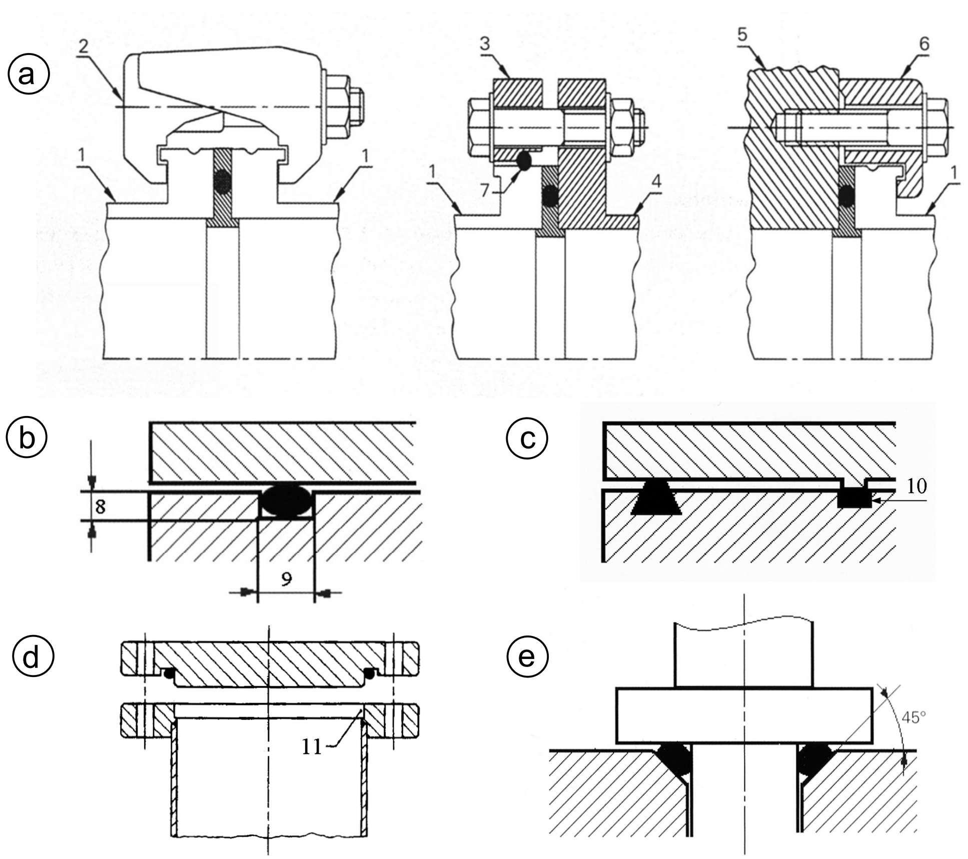

Figure 9.1
Examples of elastomer seals. a - *ISO seals with centered O-ring and clamps (left), fixed to rotatable flange with collar (middle) or bolted vacuum wall to rotatable flange with collar (right),* b - *seal with rectangular O-ring groove,* c - *seal with closed dovetail groove for positive retention of the O-ring (used in load-lock doors, etc.),* d - *self-centering flange system,* e - *seal with O-ring in corner position.* 1 - *rotatable ISO flanges,* 2 - *clamp,* 3 - *collar,* 4 - *fixed flange,* 5 - *vacuum wall,* 6 - *collar,* 7 - *circular clip,* 8,9 - *width and depth of rectangular O-ring groove (see table 9.2),* 10 - *spacer,* 11 - *centering edge.*

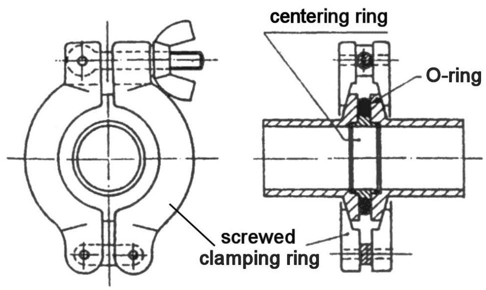

Figure 9.2
Pneurop KF (or NW) flange system.

The hardness of elastomers is expressed in the unit 'shore'. The shore is normalized to the known plastic Bakelite having a shore hardness of 100. In the coarse and fine vacuum ranges (see chapter 5, fig. 5.1), elastomers of 40-60 shore (e.g. Perbunan, neoprene, nytril) are generally used. The materials Viton and Kalrez, suitable for high vacuum applications, have a slightly higher shore hardness of 60-80. Table 9.1 gives guide numbers for the compression and volume factor to be used and to calculate therefrom the width and depth of a rectangular O-ring groove (expressed in terms of the O-ring thickness *d*) in relation to the shore hardness.

Table 9.1 Guide numbers for the required compression κ, the volume factor f and the resulting width B and depth A for a rectangular O-ring groove (expressed in terms of the O-ring thickness *d*) in relation to the shore hardness.

Shore hardness	κ	B	f	A
40-60	0.3	0.7 d	1.05	1.15 d
60-80	0.2	0.9 d	1.05	1.04 d

The thickness d is standardized to a set of fixed values by the suppliers of elastomer O-rings. Table 9.2 with accompanying figure 9.3 shows the standard sizes for d and the most suitable dimensions for rectangular grooves for elastomers as Perbunan and neoprene. For Viton (having a slightly larger shore hardness) the groove width B in figure 9.3a is chosen somewhat larger and the groove depth A smaller.

Some general observations with regard to elastomer-sealed flanges and the presented configurations:

1. A drawback of the configurations as shown in figures 9.1a and 9.2 is that both flange surfaces can be easily damaged, resulting in leakage. The flange joint in figure 9.2 is called KF or NW coupling. KF and NW are, respectively, abbreviations for the German words *Kleinflansch* (small flange) and *Nennweite* (nominal width). This flange joint is frequently used because of its simplicity and user-friendliness.