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Leak detection

8.1 INTRODUCTION

In recent decades, the importance and extent of control of the leak tightness of devices, systems, components, storage tanks, etc. has greatly increased, not only in the vacuum industry and in industries where vacuum traditionally plays an important role, but also and especially in industrial processes not directly related to vacuum activities. A multitude of general consumer products and professional devices and plants are now tested for leak tightness by more or less sophisticated methods. While in vacuum technology the control of leak tightness is focused on *leak finding* (locating the site of a leak) and repairing the leak, most industrial applications in other fields of interest beyond vacuum technology are particularly concerned with *leak proving* (approve a product as airtight or reject it as leaky) as a sophisticated method for quality control. Well-known application areas are the automotive and aircraft industry (control of cast aluminium car rims on gas-filled cavities, engine parts, fuel tanks, hydraulic systems), the packaging industry (leak tightness of vessels, tinplate work, aerosol cans), the semiconductor industry (leak tighness of IC-casings, transistors and reed relays) and refrigeration industry (tightness of cooling plants, aircon systems, etc.)

Control of leak tightness may be random or performed to all products as a step in a production process. In the first case, leak proving has the function of a quality control; in the second case all products which do not meet a predetermined tightness specification are rejected. Leak testing generally takes place not only because of economic considerations, but often also in view of the increasingly stringent environmental legislation. Thus, for instance, containers of combustible and toxic substances must meet high tightness requirements to be accepted as cargo transport. In the oil and gas industry, chemical (and nuclear) reactor technology and the refrigeration sector, high demands are made on the tightness of pipelines, storage tanks and other system components because of environmental considerations. Of course, the issue here (just as in vacuum technology) is not only leak proving, but in particular leak finding and repair.

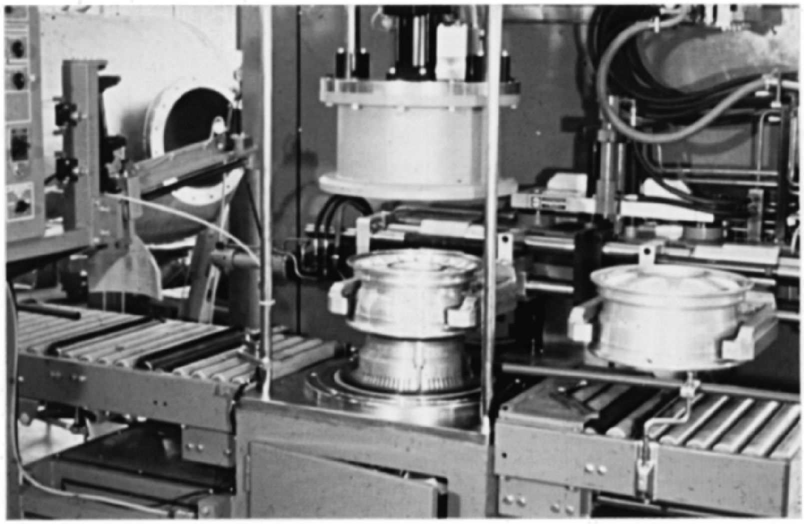

Figure 8.1
Industrial helium leak test plant for control of cast aluminium car rims on gas-filled cavities.

As a consequence of the ever growing number of economically or environmentally demanded applications of tightness control in industry and science, leak detection has developed into a more or less independent discipline. Among the currently available leak detection methods, those originating from vacuum technology take a prominent place because of their extremely high sensitivity and rapid response.

8.2 CONCEPTUAL CONSIDERATIONS; LEAK RATE

The ultimate pressure p_u in a vacuum system is determined by the amount of gas (throughput) Q to be pumped and the available pumping speed S according to the following relation:

$$p_u = \frac{Q}{S}$$

In a vacuum system where no gases or vapours are produced, the ultimate pressure is determined by the degassing of the walls and inside components, and possible leakage. Therefore, in order to correctly assess the quality of a vacuum system on the basis of, for instance, pressure decay curves and attainable ultimate pressure, prior attention should be given to identifying and minimizing these gas sources. In the following sections attention is paid to the leak tightness control of vacuum systems and components as well as leak detection and leak finding. Degassing phenomena are covered in chapter 10.

In essence, leakage as well as degassing are (undesired) gas flows and as such can be expressed in Pam^3/s (for conversion factors to other units see Appendix B, table 5). In answer to the question whether or not a vacuum system or component can be defined as 'leak tight' one needs to ensure that the system in its entirety does or does not meet a pre-set tightness requirement. A system or component is characterized as 'leak tight', when the gas flow resulting from leakage (leak rate) does not exceed a previously specified value in Pam^3/s. In setting such a tightness requirement, it should first of all be noted that absolute leak tightness does not exist. As treated in chapter 10, there will always be a natural permeation from the outside atmosphere through vacuum walls and seals. The corresponding permeation rate depends on the material choice and as such can be estimated in advance. Besides, one should be aware to question which leak rate is permissible. A leak tightness requirement must be functional in relation to the process or experiment to be carried out in the vacuum system, and not just specified "off the cuff". Reduction of the maximum acceptable leak rate requires more sensitive detection methods and generally increases the time required for leak detection and leak finding. Therefore, a higher leak tightness requirement in general is strongly cost-increasing.

Checking compliance with a predetermined leak tightness requirement is called *leak proving* or *leak testing*. Once firmly established through integral leak testing that a system or component does not meet this requirement, the impermissible leak can be searched for and localized, in order to identify and eliminate the cause. We now speak of *leak finding*.

Many reasons can be given why walls, joints or seals may exhibit leakage. As an example, drawn and rolled metals may exhibit leakage in the rolling direction; perpendicular to the rolling direction, the risk of leakage is much smaller. Plastic seals may become porous by aging (usually under the influence of air and light). Corrosion of sealing surfaces may cause leaky flange gaskets. Oxygen-containing copper may become porous under the influence of hydrogen, which reacts with the oxygen into water and thus gives rise to cracks or blisters. For walls and seals it is therefore advisable to use oxygen-free copper. Welded, melted, brazed and soldered joints may show leakage after manufacturing as a consequence of improper cleaning of the surfaces to be joined, wrong sizing, too little solder or incorrect temperature treatment. Furthermore, leakage can be caused by mechanical stress during assembly and/or bakeout.

If no (external) leak can be detected and the system nevertheless shows all the symptoms of leakage (too high ultimate pressure, residual gas spectrum with high peaks for nitrogen and oxygen, see figure 5.39), an enclosed gas volume in the vacuum system can be the cause of the problems. We speak in this case of a *virtual* leak. A well-known example of a virtual leak is gas leaking from a blind hole along the thread of a screwed bolt. In this particular case the 'leakage' problem can simply be avoided by drilling a small hole through the center of the bolt or file a flat side at the screw thread. A more problematic appearance

of virtual leakage occurs in the case of a gas inclusion in combination with a long capillary path to the atmosphere. This may happen, for instance, if a crack occurs in the bottom of a blind hole in the vacuum wall. The path from the outside atmosphere to the blind hole and along the screw thread of the bolt can then be so resistant that it has all the features of an inclusion and thus seems to be virtual. Generally in case of a virtual leak, leak testing and leak finding fails.
We conclude that no simple standard protocol exists for leak detection and leak finding in vacuum systems and components, and as a rule expertise, ingenuity and above all patience are required to obtain reliable results.

8.3 LEAK DETECTION METHODS

In order to be able to carry out leak tightness control of a vacuum wall, one must be able to apply a tracer at one side of the wall, while at the other side of the wall sensitive detection of this tracer must be possible. In addition, a pressure difference across the wall is necessary, in order to realize the transport of the tracer through the leak. Basically, four different methods can be distinguished:

a. Pressurizing (inside-out) methods: The object to be tested is pressurized inside by a tracer gas or liquid. As a tracer different liquids and gases are eligible. The object is probed externally with a sampling probe connected to a leak detection system. The sensitivity of the method increases with excess pressure and decreases when diluted tracers are applied.
b. Reduced pressure (outside-in) methods: The inside of the object to be tested is brought to a reduced pressure and a tracer is sprayed (gas) or put over (liquid) the outside of the object. Tracer gas or vapour entering the object through a leak is evidenced by a connected leak detector. Here too, several liquids and gases come into account. The sensitivity increases with decreasing inside pressure.
c. Atmosphere (inside-out) method: This method is especially developed for leak testing of sealed or welded components that cannot be connected straight onto a leak detection system and for which extreme tightness requirements apply (e.g. pacemakers and other medical implants). The casing of these components is sealed or welded in a tracer gas at ambient pressure (1 atm). Thus, after close off, the volume inside the casing is filled with tracer gas at atmospheric pressure. Subsequently, the component is put in a vacuum chamber equipped with a leak detector. In case of a leak, tracer gas is drawn out of the casing into the chamber and the leak detector will respond.
d. Bombing: This method is applied to sealed devices and components, for which less severe tightness requirements apply (e.g. cavity-type integrated circuits, medicine strips, waterproof watches and cameras). After sealing, the component is placed inside a so-called 'bombing chamber' which is pressurized with a tracer gas. The tracer will