Guideline
Industrial Leakage Testing

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Rudersberg, in January 2010
Jochen Müller

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1 PREAMBLE

The following guideline was prepared for industrial practitioners, which during their work are entrusted with the selection and the operation of leakage test equipment. It shall facilitate their affairs by showing the advantages and limits of the different test methods, by giving tips for design and operation of these facilities.

A guidance to evaluate the test quality and remarks to regularly check of the test quality shall help the user to ensure a stable good quality in his area of response.

The author of this guideline is working for more than twenty years in the field of automation of production and test equipment. In the last 15 years he has planned some hundreds of test equipment for industrial leakage test, realised them and brought them to production.

Often the user told him, that leakage testing may have to do with black magic. The task of this guideline is, to clear the background of quality of the leakage testing and make it easier and more intelligible.

2 TIGHTNESS AND LEAKAGE

2.1 Why Leakage Testing?

The importance of the characteristic “tight“ in the every days life normally is realised only very secondarily and a lot of people can not imagine, how many products are leak tested.

But if doing not,

- untight piping and armatures for fuel, oil and gas would cause a very high risk of fire and explosion,
- untight food packaging would cause decomposed products,
- refrigerators, heaters, washing machines, gas stoves and other home appliances would not work correct,
- cars with untight oil-, fuel- and water- systems would be liable to an increased abrasion and would endanger the environment
- and in public health sector untight injection systems would be the reason for the injection of air and mortal embolisms and the medical effect of untight inhalation systems would be reduced.

The above mentioned products and numerous others are tested during production for leaks of single components, subassemblies or complete.
This is the reason why leak testing is one of the most prevalent testing method during industrial production.

2.2 What Means “Tight“?

But what is really meant with „tight“? In this chapter shall be tried to clarify the immense span width of this term.

It is beyond all question: the tyre, shown in illus. 1, is untight and not useable to continue the journey.

Illus. 1: untight tyre

But if you pick up the example of the tyre and observe the pressure change in the tyre over different periods, the span at least rudimentary will become apparent.

A pressure drop of 0.1 bar per year surely not will be considered as untight. But it represents a leakage rate of 0.0074 cm³/min.

Also a pressure drop of 0.1 bar per month disappears in the normal measuring inaccuracy and is not be experienced as troublesome. In this case the leakage rate represents 0.09 cm³/min.

As a real damage of the tyre a pressure drop of 0.1 per day will be experienced. The leakage rate is 2.7 cm³/min.

If the tyre looses 0.1 bar per hour, which represents a leakage rate of 64.7 cm^3/min, each car driver will let it repaired in a work shop. But normally he will drive with the damaged tyre and preferably adjust the air pressure from time to time.

A repair or the change of the tyre on site is not necessary before a pressure drop of 0.1 bar per minute.
The leakage rate now is already 3,880 cm^3/min.

You can look at the tyre also under an other view:
Everybody knows the method, to find the leakage of a bicycle wheel by holding the inner tube under water and searching for ascending air bubbles. Normally a wheel then is be classified as untight, if the first bubble ascends after a short observation period.

At the car tyre with the pressure drop of 0.1 bar per year, this would be the case after 33 seconds. From the above point of view, the tyre would be untight..
Of course the tyre with a pressure drop 0.1 bar per minute would cause a real whirl pool. There will ascend 924,000 bubbles per minute.

In table 1 pressure drop, leakage rate and bubbles per minute are juxtaposed and compared with usual used limit values of well-known products.

pressure drop	leakage rate [cm³/min]	bubbles per minute	example of use
0.1 bar / minute	3,880	924,000	**tight** for car exhaust silencer
0.1 bar / hour	64.7	15,400	
0.1 bar / day	2.7	640	**water-proof**
0.1 bar / week	0.39	93	**untight** for special valves in chemical industry
0.1 bar / month	0.09	21	
0.1 bar / year	0.0074	1.8	**untight** for the most fuel containing parts

Table 1

2.3 Admissible Leakage Rates

After consideration of table 1 nearly compulsory the question comes up, who fixes these admissible limits, or where they could be found.

Unfortunately in this area exists no standard and only a few directives, which could be used for the fixing of a limit.

Only DIN EN 60529 (NEMA IEC 60529) gives by fixing the IP-protection-classes a little indication about the requirements for tightness. But it references its definitions mostly to the environmental conditions of the usage and the test.

2.3.1 Tightness Requirements Basing on the Usage

In the last years however the following, nearly in general accepted and used limits have been established for the primary applications .

characteristic	admissible air leakage rate	
	from	to
waterproof	0.5 cm³/min	12 cm³/min
oil-tight	0.6 cm³/min	4.5 cm³/min
fuel-tight	0.0006 cm³/min	3.0 cm³/min
gas-tight	has to be deduced from the usage	

Table 2: usual values for admissible air leakage rates

Remark: The extremely small value at „fuel tight“ bases on the American directive US-CAR, which limits the total emission of HC from fuel (evaporation) to 150mg per 24h (Level II). From 2018 the limit will be reduced to 54mg per 24h (PZEV).
The higher limit of 4.5 cm³/min represents liquid-tight against fuel.

How multifarious the far-ranging “gas-tight“ can be, shall shown with help of the following both examples:

A ball, which is used during soccer world championship has to have a circumference between 68 cm and 70 cm. Its pressure has to be in the range between 1.1 bar and 0.6 bar.

This ball then is “gas-tight“ according the requirement, if the pressure does not drop for more then 0.5 bar during a match including preparation time and rest period.

The volume of the ball with a circumference of 70 cm is 5.8 litres. At an inner pressure of 1.1 bar relative overpressure, it includes an air volume of 12.18 sl
If the pressure drops to 0.6 bar relative overpressure, the volume of the included air is reduced to 9.28 sl. Therefore this ball has a just acceptable gas-tightness, if it does not lose more than 2.9 sl air within 3 hours.

This equals a leakage rate of 2,900 cm^3 / 180 min and that is 16.1 cm^3/min.

A totally different value is represented by „gas-tight“ if we evaluate a gas-assisted shock absorber. Its volume is 500 cm^3 and the pressure may drop from 16 bar to 15 bar within 10 years.
The leakage rate is calculated as follows:

(Start standard volume – end standard volume) / time
(500*(16+1) – 500*(15+1)) Ncm^3 / (10*365*24*60 min)

The acceptable gas-tightness of the gas-assisted shock absorber in this case is given at a leakage rate of 0.000095 cm^3/min.

Remark:
The above for the first time used units sl and scm^3 represent the real volume of a gas under standard conditions (1013 mbar / 0 °C).

2.3.2 IP-Protection Classes

DIN EN 60529 (NEMA IEC 60529) demands at definition of the protection classes against water (2. index): protection against ingress of water in harmful quantity.

It differentiates:

Protection Class	Protection against	Ancillary Conditions
IPX1	dripping water	vertical
IPX2	dripping water	± 15° from vertical
IPX3	spraying water	with 10 l/min ± 60° from vertical
IPX4	splash water	10 l/min from all directions
IPX5	jet of water	jet of 12,5 l/min from all directions
IPX6	heavy jet of water	heavy jet of 100 l/min from all directions
IPX7	temporarily immersion	depth: 1000 mm, durance: 30 min
IPX8	longer immersion	according demand of the customer

Additionally, there exists for the automotive area:

IPX4k – protection against splash water from all sides with higher pressure.
IPX6k – protection against heavy jet of water with higher pressure.
IPX9k – protection against water during high-pressure or steam cleaning.

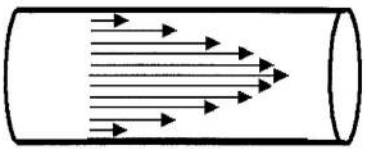
It is possible to meet IPX1 to IPX3 with help of a labyrinth seal (rebated joints, overlaps or similar).
The requirements of IPX4 to IPX9k in practice mean waterproof, but with big differences in pressure from outside and in the duration.
Realise, that the water pressure at IPX6, IPX6k and IPX9k is higher then at pure immersion.
Limits of admissible leakage rates are also not defined in this standard.

2.4 Background of a Leak

Table 2 shows comparatively wide spans of admissible air leakage rates for all liquid tightness. For the better understanding of the reason and to be able to choose the correct admissible leakage rate for a special component, a closer examination of a leak is needed.

Extremely simplified, a leak is a tube with circular profile, whose length is defined by the material thickness of the part. The medium passes through this tube.

If a laminar flow is assumed, the flow rate can be calculated with help of the following equation:



$$Q = \frac{r^4 * \pi * \Delta p}{8 * \eta * l}$$

r -	radius of the tube	η -	dynamic viscosity
Δp -	pressure difference	l -	length of the tube

So, at a laminar flow, the flow rate depends on the diameter and the length of the leakage “tube” plus the dynamic viscosity η of the streaming medium.

At geometrical equal profiles of leaks the leakage flow at a thin walled part will be higher a than at a thick walled part.

Another essential factor of influence and an important reason for the usage of gases for the test of liquid tightness is the highly different dynamic viscosity.
Because the amount, escaping a leak is direct proportional to the dynamic viscosity, under the same conditions the air stream is approximately 60 times higher than a water stream and can be detected in a shorter time.

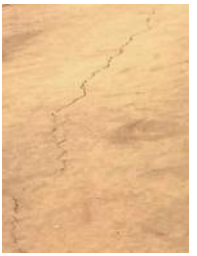
In case of benzol, the air stream is only 35 times higher. This is the reason, why the air equivalence of “waterproof“ is clearly higher than the equivalent of “fuel-tight”.

dynamic viscosity η [mPa*s]			
Gases		Liquids	
Helium	0.0186	Benzol	0.601
Air	0.0171	Lacquer	approx. 100
Sulphur hexafluoride	0.0156	Motor oil (at 100°C)	approx. 6 - 7
Hydrogen	0.0084	Water	1.000

Table 3: dynamic viscosity

Also the shape of the leak has an essential influence to the amount of the streaming fluid. The shape of a tub, which was the basis for the above thoughts, is extremely seldom in practice.

Real leaks rather have the following shapes:



Illus. 2:
Crack in a ceramic surface

Illus. 3:
Aluminium-casting fault

- fine-grained crack (for example in plastics or in cast part),
- exiguous chinks and cracks (for example at bonding- and weldseams),
- capillaries and cavities (for example at cast parts)

Illus. 4:
Shrinkage cavity

Illus. 5:
Fracture in a welded joint

These leakage shapes are the reason, that more turbulent flow conditions are generated.

The turbulent flow is the movement of liquids and gases, in which swirls in all magnitude can occur. This form of flow is characterised by mostly three-dimensional, seemingly random, unsteady movements of the fluid.
This turbulence causes a flow resistance, which constricts the flow through the leak and reduce the amount of leakage.

The transition from laminar (with low resistance) to the turbulent (with high resistance) flow results like in a running water from the friction of the streaming fluid at the border of the flow channel and at obstacles.

Illus.6:
Turbulent flow in a brook

The appearance of a turbulent flow will be facilitated, among other reasons by

- small cross section of the leak,
- high surface roughness at the part and
- viscidity of the streaming fluid.

Another effect, which constrains the streaming out is the surface tension of liquids. It can be so high, that it completely prevents the flow of the liquid into a small crack. As an example may serve the mercury, which has such a high surface tension, that it stays nearly a ball, if it lies at a surface.

liquid	surface tension
benzol	28,90 x 10^{-3} N/m
silicon oil	18,50 x 10^{-3} N/m
water	72,75 x 10^{-3} N/m

Table 4: surface tension

How table 4 shows, the surface tension of the most important liquids, which are relevant for leakage testing, is highly different. This is another reason, why the air equivalence for liquid tight is different from liquid to liquid.

In practice this means:
A liquid flows much worse through real leaks with high roughness of its wall and small cross section than a gas. But it also means, that the flow of liquids in this case is highly different.

In summary applies:

1. A circular hole in the wall of a part causes a much higher leak as a crack with the same cross-sectional area .
2. The thicker the wall of a part is, the more the streaming out is constrained.
3. Liquids with high dynamic viscosity and high surface tension permeate leaks worse than those with small dynamic viscosity and small surface tension.

4. Leaks in all shapes are more tight against liquids as against gases.

This facts together have to be considered when the thoughts are made, if a smaller or a higher air leakage rate from table 2 is chosen for the definition of the limit of a test.

If the possibility of circular leaks in thin smooth walls exists, smaller air leakage limits have to be fixed. If at the part at the most small cracks in a thick wall with rough surface have to be expected, the limits can be set higher.

2.5 Physical Dimensions of a Leak

To describe the leakage rate, in general one of the three following physical definitions is used:

1. *Specification of the leakage rate as pressure decay.*
   This definition only can be used, if the leakage test is made with one of the pressure gauging methods.
   But the definition of a limit in mbar/min is not complete. For definition of the admissible leakage rate the description of the total volume is needed. This consist of the sum of the volumes of specimen, test fixture, test tubes and test equipment.

2. *Specification of the leakage rate as flowrate.*
   This variant is the almost familiar for small and middle leakage.
   Normally the units ml/min or cm^3/min are used but other units for volume and time are also possible. An

overview and help for the conversion gives a table in the appendix.

3. *Specification of the leakage rate as a pv-value.*
   This is the definition according the standard DIN EN 1330-8 (BS EN 1330-8). The corresponding SI-unit is Pa * m³ / s. But in praxis the unit mbar * l / s is more used. The change between these both terms is a pure recalculation of the units:

   $$1 \text{ mbar l /s} = 0{,}1 \text{ Pa m}^3\text{/s}$$

   Especially in the area of small leakage, which are tested with help of gas verification methods the declaration of a leakage rate basing on a pv-value is very popular.
   A leak with the size of “1 mbar l / s” causes a pressure drop of one mbar per second in a volume of one litre.

It is possible to recalculate the different specification variants to each other, if during leakage test the following conditions are assumed:

- Outside of the tested part are ambient conditions.
- The temperature does not change during test.

Formula for the conversation between flowrate and pressure decay

(Approximation without consideration of temperature changes)

Evaluation Method:

$$\mathbf{p_1 * V_1 = p_2 * V_2}$$

(Boyle-Mariotte's law)

$\Rightarrow p_{start} * V_{start} = P_{end} * V_{end} + p_{leak} * V_{leak}$

because $V_{start} = V_{end} = V_{device\ under\ test} + V_{system} = V_{test}$

and $p_{leak} = 1.013$ bar (ambient pressure)

$\Rightarrow V_{test} * (p_{start} - p_{end}) = V_{leak} * 1.013$ bar

or

$$V_{leak} = \frac{V_{test} * \Delta p}{1.013\ bar}$$

The scaling to the flowrate is done by including the test time:

$$\boxed{Q_{leak} = \frac{V_{test} * \Delta p}{t_{test} * 1013mbar}}$$

Or rearranged to Δp:

$$\boxed{\Delta p = \frac{Q_{leak} * t_{test} * 1013mbar}{V_{test}}}$$

Conversion from a pv-value to a flowrate

At a pv-rate of 1 mbar l/s the pressure inside a volume of 1 litre (1000 ml) changes by 1 mbar per second.
This is caused by a flow of 1 scm³ per minute which escapes out of this volume with 1000 ml under 1000 mbar.
(1 scm³: 1 cm³ under standard conditions: 1013,25 mbar / 0°C)

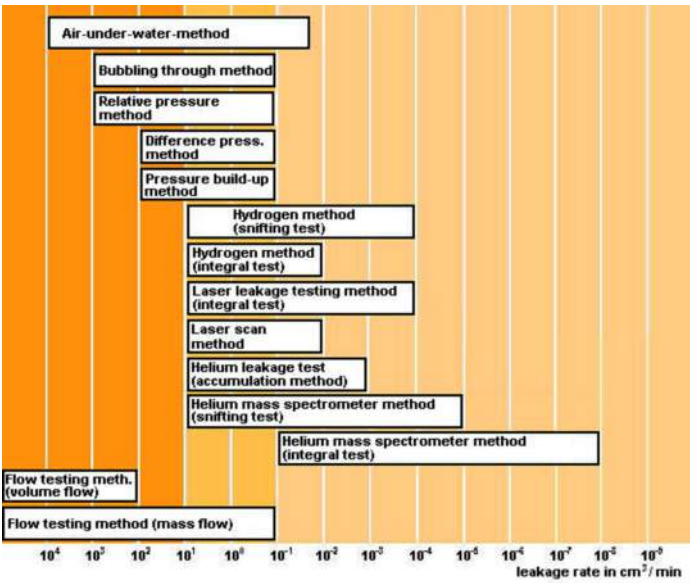
Under production conditions therefore it is approximately:

1 mbar l/s= 1 cm³/s = 60 cm³/min

A leakage rate of for example $1 * 10^{-3}$ mbar l/s then equals a flowrate of 0,06 cm³/min.

3 METHODS OF LEAKAGE TESTING

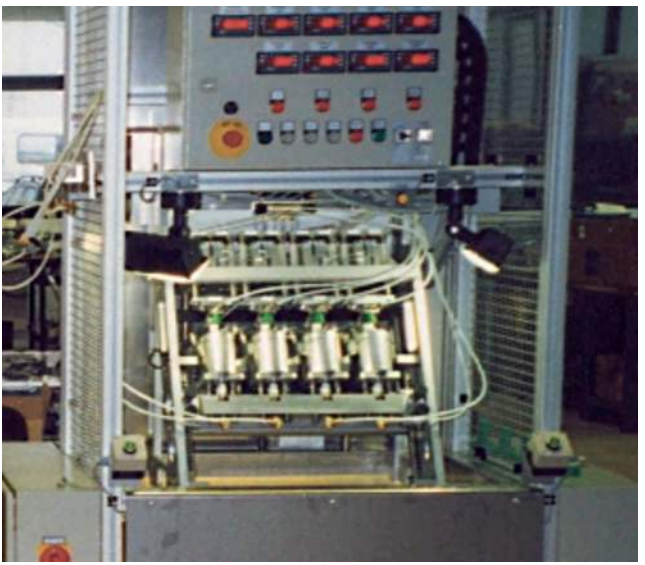
Below the most common methods of leakage testing shall be introduced and described.



Illus. 7:
Application area of the most used test methods

3.1 Air-Under-Water-Method

Method:
The specimen is tightened, immersed in water, seldom in other liquids, and filled with pressure. At leaking the test gas bubbles up. The bubbles at point of leakage are mostly observed visually or, in seldom cases detected by a ultra-sonic sensor equipment.



Illus. 8:
State-of-the-art air-under-water test bench with additional internal tests

Test medium: pressurised air
Detectable leakage: > 0.1 cm^3/min

Advantages:
- The detection of the point of leakage is very easy. Thereby at purely manual test benches it is possible, to continue the work, even if there is a small leakage at the clamping and sealing fixture because of some deterioration.
- Mostly more than on specimen are tested in parallel in one cell. This enables a high throughput.

Disadvantages:
- The specimen get wet and have to be dried with high effort before the subsequent use. Sometimes they have to be conserved.
- The method is unusable for moisture-sensitive parts.
- The quality of testing depends to 100% to the operators concentration and care.
- Caused by unsteady quality of the liquid and by different profiles of the leaks, the characteristic of the bubbles may differ. At worst case even big bubbles fit at the surface of the part and can not be realised by the operator.
- A quantitative leakage rate determination is not possible.
- The automatic documentation of the test results is not possible.
- Defined reject part handling is not possible.
- The test benches require a high expenditure because of the necessity of the usage of moisture-resistant and noncorrosive materials and components.

- The guaranty of a good quality of the liquid is costly.

Remarks:

- By addition of releasing substances (e.g. soap or washing-up liquid) the surface tension can be reduced. This helps, that more and smaller bubbles come up, which can be better detected.
- The cell of air-under-water test benches have to be illuminated extremely good to ease the detection of the air bubbles.
- The concentrated searching for bubble is very stressful for the operator. If possible, a working organisation should be found, that the operator can change his working field after max. 2 hours.
- An automated check is necessary to ensure that the specimen during the test are really filled with pressurised air.
- Especially in case of higher test pressure the operator has to be protected against bursting parts or bursting connecting tubes.

3.2 Bubbling Through Method

Method:
The specimen is tightened and filled with a constant air pressure. The air, escaping by leakage is refilled. During this it streams through a water filled inspection glass. If bubbles are rising in this glass, a leakage is shown. This method is the inversion of the air-under-water-method.

Illus. 9: Bubbling through unit

Test medium: air
(overpressure or vacuum)

Detectable leakage: > 0.1 cm^3/min
(depending on the pressure)

Advantages:
- Very cost-efficient, simple and robust method.
- The specimen remain dry.
- The test method is useable for overpressure and vacuum.

Disadvantages:
- The quality of testing depends to 100% to the operators concentration and care.

- A quantitative leakage rate determination is not possible.
- The automatic documentation of the test results is not possible.
- Defined reject part handling is not possible.
- Caused by unsteady quality of the liquid the characteristic and the size of the bubbles may differ.

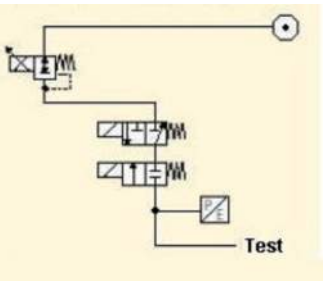
Remarks:
- The inspection glass is positioned in the air inlet of the specimen and is filled with the test pressure. This entails, that the bubbles are pressurised. The higher the pressure, the less or the smaller bubbles are visible at the same leakage. Using vacuum, the bubbles are artificially enlarged.
- Because of its high flexibility, this method is used mainly for maintenance purposes or in testing small quantities.

3.3 Relative Pressure Method

The name relative pressure method is derived from measuring the pressure relatively to the ambient pressure. If it is measured absolutely, basing on absolute vacuum, it may named “absolute pressure method”.
Several manufacturers use the names “pressure changing method” or “pressure difference method”. But with this names the used method of measurement is not defined clearly.
The following description however is valid for all of these methods.

Method:
The specimen is tightened and the test volume, consisting of specimen, test fixture, the air inlet hose and the test unit itself is filled with air or more seldom other gases and blocked. It is also possible to evacuate it.
The pressure change originating from a leakage is measured and valued.

Illus. 10:
Simple, low-cost relative pressure testing unit



Illus. 11:
Functional diagram of a relative pressure testing unit

Test medium: air, more seldom nitrogen or other gases (overpressure or vacuum)

Detectable leakage: > 1 cm^3/min, depending on test pressure and test volume

Advantages:

- Test units, basing on the relative-pressure method are designed very simple. They are cost-efficient and robust.
- Due to the test cycle with fixed constant times and monitored pressure, which is defined in the test device, all tests are running under the same repeatable conditions.
- The evaluation is independent from the operator.
- Test units, basing on the relative pressure method normally are equipped with interfaces, which allow the integration in an automatic process.
- The exact measurement of the pressure change allows a quantification of the leakage rate. The allowed tolerance can completely used.
- The test results can be automatically documented, if the device is equipped with a suitable interface.

Disadvantages:

- Temperature changes during the real measuring time cause pressure changes which influences the test result.
- With elastic specimen the pressure change caused by the leakage can partially be compensated by the elasticity of the specimen.
- The measuring area of the pressure sensor of a relative pressure testing unit covers the whole test pressure range. The resolution of the smallest pressure changes is thereby only possible within limits.

Remarks:

- Pressure changes are directly proportional to the volume if the leakage rate is constant. The test of parts with high volume with the relative pressure method may critically. It should be tried to hold the test volume as small as possible by using a filling piece.

3.4 Difference Pressure Method

Leakage tests according to the difference pressure method are actually the most often carried out leakage tests in the industrial serial production.

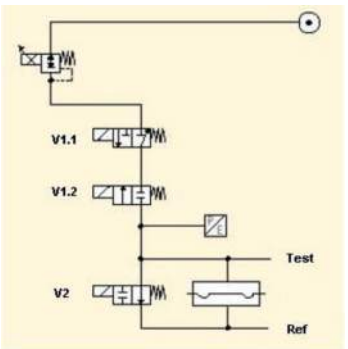
Illus. 12:
State-of-the-art difference pressure unit

Method:

The specimen is tightened and the test volume, consisting of specimen, test fixture, the air inlet hose and the test unit itself is filled with air or more seldom other gases and blocked. It is also possible to evacuate it.

The pressure change originating from a leakage is measured in comparison to a sealed reference-volume and valued.

Test sequence:
The test cycle includes the steps “Filling”, “Stabilisation”, “Testing” and “Deflating”. Usually the steps are controlled by time.



Illus. 13:
Functional diagram difference pressure unit

During the filling time the complete test- and reference-volume of the device is filled with pressurised air or vacuum by switching the valves V1.1 and V1.2.

After end of the filling time, the filling valves are closed and the whole test- and reference-volume can stabilise (stabilisation time). During that time thermodynamic effects, which arise from filling, shall balance as good as possible. The test valve V2 is opened during stabilisation time.

After the end of the stabilisation time the test valve is closed. Now the test pressure is monitored. During the subsequent testing time only the pressure difference between test-volume and reference-volume is measured.

During the step “deflating” test- and reference-volume are brought back to ambient pressure.

Test medium: air, more seldom nitrogen or other gases (overpressure or vacuum)

Detectable leakage: > 0.1 cm^3/min, depending on test volume

Advantages:

- Because of the special measurement method the measurement resolution is independent from the test pressure. At state-of-the-art difference pressure test units the resolution is 0.1 Pa (0.001 mbar).
- Due to the test cycle with fixed constant times and monitored pressure, which is defined in the test device, all tests are running under the same repeatable conditions.
- The evaluation is independent from the operator.
- Test units, basing on the difference pressure method normally are equipped with interfaces, which allow the integration in an automatic process.
- The exact measurement of the pressure change allows a quantification of the leakage rate. The allowed tolerance thereby can completely used.
- The test results can be automatically documented, if the device is equipped with a suitable interface.

Disadvantages:

- Temperature changes during the real measuring time cause pressure changes which influences the test result.

- With elastic specimen the pressure change caused by the leakage can be compensated partially by the elasticity of the specimen.

Remarks:
- Pressure changes are directly proportional to the volume if the leakage rate is constant. The test of parts with high volume with the difference pressure method may critically. It should be tried to hold the test volume as small as possible by using a filling piece.
- A test unit basing on the difference pressure method has to be tested frequently for plausibility of the measurement values with help of a well-known specimen or a test dummy (see also chapter 8).

3.5 Pressure Build-up Method

The pressure build-up method is often used, if a direct measurement in the test volume is not possible or makes no sense from meteorological view. This for example is fact, if the test volume is very big or the test pressure very high.
In this cases a best possible fitting hood is placed around the specimen. Then the pressure change in the hood is measured and valued.

Method:
The specimen is tightened and filled with pressurised air or in seldom cases evacuated and placed under a sealed hood. The pressure change under the hood is measured, valued and represents the dimension of a leakage.
The measurement can be done according the relative pressure method or according the differential pressure method.

Illus.14:
Test hoods for pressure build-up method

Test medium: air, more seldom nitrogen or other gases (overpressure or vacuum)

Detectable leakage: > 0.1 cm³/min, depending on test method, test pressure and test volume

Advantages:

- A faster test is possible because the measurement already can be started during the specimen is filled. The stabilisation time can be dropped with dimensionally stable specimen.

- If a very high test pressure is used, the thermodynamic effects for the surrounding volume in the hood are much smaller than for the test volume.
- Often it is possible to generate a smaller test volume with help of a close fitting hood than it is in the inner of the specimen.
- Due to the test cycle with fixed constant times and monitored pressure, which are defined in the test device, all tests are running under the same repeatable conditions.
- The evaluation is independent from the operator.
- The integration in an automatic process is possible.
- The exact measurement of the pressure change allows a quantification of the leakage rate. The allowed tolerance can be thereby completely used.
- The test results can be automatically documented, if the device is equipped with a suitable interface.

Disadvantages:

- Due to the sealing of the specimen under a hood, which itself has to be tight against ambient, this method causes high mechanical complexity. An additional effort is generated for diagnostics of problems with the sealing under the hood.
- If the hood becomes leak against ambient, there is a high risk of mismeasurement. To avoid this, additional supervising methods have to be implemented
- Temperature changes during the real measuring time cause a pressure change which influences the test result.

- With elastic specimen the pressure change caused by the leakage can be compensated by the elasticity of the specimen partially.

Remarks:

- At test equipment according the pressure build-up method has to be monitored in each cycle to ensure the tightness of the hood against ambient. This for example can be done by working with vacuum in the hood while the specimen is filled with overpressure.
  A second method is, to produce a slight overpressure during the closing of the hood. This can be monitored and has to be at the same level at each cycle.
- Pressure changes are directly proportional to the volume if the leakage rate is constant. Also at test equipment according the pressure build-up method it is necessary hold the test volume as small as possible.
- The test unit has to be tested frequently for plausibility of the measurement values with help of a well-known specimen or a test dummy.

3.6 Hydrogen Method (Snifting Test)

Method:

For the test forming gas 95/5, a non-combustible mixture from 95% nitrogen and 5% hydrogen is filled into the test volume under overpressure. The gas, which is escaping

Illus. 15: Hydrogen snifting unit

through leakage is detected by a manually operated hand probe.

Test medium: Forming gas (5 % Hydrogen / 95 % Nitrogen)
Detectable leakage: >0.0001 cm³/min

Advantages:
- Very small leaks are detectable.
- The test method is simple in use.
- Temperature and elasticity have no influence to the test result.
- It is easy to localise the point of leakage with help of the hand probe.
- At a test with hydrogen the risk of contamination of the background in the working environment is the lowest of all tracer gas methods.
- Hydrogen has an extremely low dynamic viscosity and is able to pass through leaks better than all other gases.
-

Disadvantages:
- The natural concentration of 0.5 ppm hydrogen in the atmosphere is a limit for the test.
- This method is often not usable for testing plastic parts because some of them have a high hydrogen permeability.
- If the probe causes small damages of anodised aluminium surfaces, it is possible, that a incorrect measurement signal is produced.
- The tracer gas escapes from the leak as a cloud. The measurement of the gas concentration as a value of the leakage rate depends from the distance between the

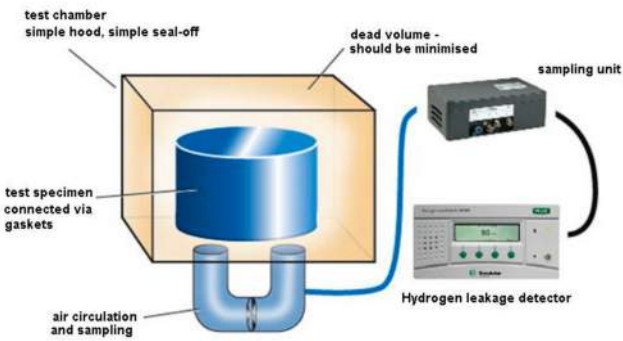
probe and the point of leak. In manual operation therefore it is impossible to do a quantification of the leakage rate.
- Forming gas is used as a protection gas in other industrial processes. If such a process works near the test station, the usage of the hydrogen method is not possible.
- The quality of testing depends to 100% to the operators concentration and care.
- The automatic documentation of the test results is not possible.
- Defined reject part handling is not possible.

Remarks:
- It is absolutely necessary to ensure an accurate and complete filling of the test volume with forming gas. The test volume therefore should be flushed with the tracer gas or should be first evacuated and then be filled.
- After the test, the tracer gas has to be removed from the working environment in a controlled way. Otherwise there is a risk of rising a background concentration, which could disable the further testing.

3.7 Hydrogen Method (Integral Test)

Method:

The specimen is tightened, filled with pressurised forming gas 95/5 and placed under a separating cover. The volume under the cover is swirled continuously to get a homogeneous mixture of the gas, escaping through leaks and the air under the cover. From this mixture a small portion is continuously sucked to the hydrogen sensor, which is able to detect smallest traces of gas.



Illus. 16:
Configuration of a hydrogen leak test(integral test) in principle

Test medium:	Forming gas (5 % Hydrogen / 95 % Nitrogen)
Sensitivity:	1-2 ppm Hydrogen in the gas mixture.

Advantages:

- Hydrogen has an extremely low dynamic viscosity and is able to pass through leaks better than all other gases.
- The test is running in an automatic test bench under fixed conditions according time and pressure. Therefore the test results are independent from the operators concentration and care and better repeatable.
- Temperature and elasticity have no influence to the test result.
- After a scaling of the factor gas concentration / leakage rate, this method supports a quantifiable leakage rate detection.
- The test results can be automatically documented.
- The test cover may be designed simple, is therefore economic and it is not necessary, to have vacuum in it.
- At tests with hydrogen the risk of contamination of the background in the working environment is the lowest of all tracer gas methods.

Disadvantages:

- The natural concentration of 0.5 ppm hydrogen in the atmosphere is a limit for the test.
- This method is often not usable for testing plastic parts because some of them have a high hydrogen permeability.
- Forming gas is used as a protection gas in other industrial processes. If such a process works near the test station, the usage of the hydrogen method is not possible.

Remarks:

- It is absolutely necessary to ensure an accurate and complete filling of the test volume with forming gas. The test volume therefore should be flushed with the tracer gas or should be first evacuated and then be filled.
- After the test, the tracer gas has to be removed from the working environment in a controlled way. Otherwise there is a risk of rising a background concentration, which could disable the further testing.

3.8 Laser Leakage Testing Method (Integral Test)

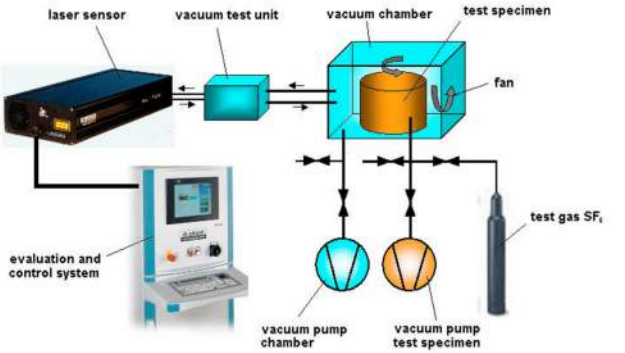
Method:

The specimen is tightened, filled with pressurised test gas and placed under a good fitting hood. The volume under the hood is evacuated in order to disperse traces of test gas, escaping through leaks, fast and homogeneously in the whole volume under the hood.

After an accumulation time a sample of the hoods atmosphere is taken and analysed for test gas traces.

Test medium: Mixture from air or nitrogen with mostly small percentage of sulphur hexafluoride (SF_6).

Detectable leakage: >0.001 cm^3/min



Illus. 17: Function of a laser leakage test in principle

Advantages:

- The test is running in an automatic test bench under fixed conditions according time and pressure. Therefore the test results are independent from the operators concentration and care and better repeatable.
- Temperature and elasticity have no influence to the test result.
- After a scaling of the factor gas concentration / leakage rate, this method supports a quantifiable leakage rate detection.
- The test results can be automatically documented.
- Very small leaks are detectable.
- It is not necessary to use high-vacuum during this test. Therefore it is possible to use low-priced valves and vacuum pumps.
- The sensor is robust and not sensitive against air pollution and moisture.

- Due to the low test gas concentration, mostly the costs for the test gas consumption are low.
- SF_6 is not present in the atmosphere. Thereby, there is no risk of disturbances due to the natural percentage.

Disadvantages:

- Due to the high quality sealing of the specimen under a hood, which itself has to be very tight against ambient, this method causes a high mechanical complexity. An additional effort is generated for diagnostics of problems with the sealing under the hood.
- High risk of contamination of the background in the working environment and of the test equipment in case of wrong usage, defects and very rough leaks.
- Costly instrumentation.
- Sulphur hexafluoride is a climate affecting greenhouse-gas and should, if at all, released to the atmosphere only in smallest amounts.

Remarks:

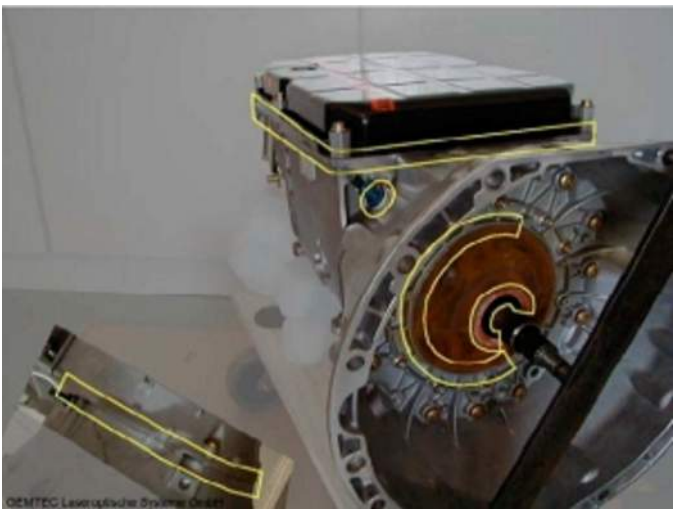
- It is absolutely necessary to ensure an accurate and complete filling of the test volume with the test gas. The test volume therefore should be first evacuated and then be filled.
- After the test, the tracer gas has to be removed from the working environment in a controlled way. Otherwise there is a risk of rising a background concentration, which could disable the further testing.
- Especially at tests with sulphur hexafluoride, the usage of a gas recycling equipment is strictly recommended. Then the amount of escaping gas to the atmosphere and the costs can be reduced.

3.9 Laser Scan Method

Method:

The specimen is tightened, filled with pressurised test gas and scanned with a laser beam, during standing free in the working area.

If the laser beam impacts smallest traces of gas, photo acoustics effects occur, which are detected with a microphone and combined with the position of the beam. Together with a camera shot, a picture can build, on which the escaping gas cloud is shown.



Illus. 18:
Laser scan shown with marked inspection area

Test medium: Mixture from air or nitrogen with mostly small percentage of sulphur hexafluoride (SF_6).

Detectable leakage: >0.01 cm³/min

Advantages:

- This is the only method, which allows a automatic localising leakage test at big and very complex parts, e.g. complete assembled motors or gearboxes.
- The tests are running in an automatic test bench under fixed conditions according time, pressure and scan area. Therefore the test results are independent from the operators concentration and care and repeatable.
- Temperature and elasticity have no influence to the test result.
- The test results can be automatically documented.
- It is not necessary to use high-vacuum during the test. Therefore it is possible to use low-priced valves and vacuum pumps.
- SF_6 is not present in the atmosphere. Thereby, there is no risk of disturbances due to the natural percentage.

Disadvantages:

- High effort for instrumentation and long cycle times, which militate against the usage of this method in serial production.
- High risk of contamination of the background in the working environment and of the test equipment in case of wrong usage, defects and very rough leaks.
- Extremely costly instrumentation.
- It is extremely difficult to find the correlation between the concentration of the test gas at any point of the

cloud and a well known leakage rate. Therefore the scaling of the system and a quantification of the leakage rate is difficult.
- Sulphur hexafluoride is a climate affecting greenhouse-gas and should, if at all, released to the atmosphere only in smallest amounts.

Remarks:
- It is absolutely necessary to ensure an accurate and complete filling of the test volume with the test gas. The test volume therefore should be first evacuated and then be filled.
- After the test, the tracer gas has to be removed from the working environment in a controlled way. Otherwise there is a risk of rising a background concentration, which could disable the further testing.
- Especially at tests with sulphur hexafluoride, the usage of a gas recycling equipment is strictly recommended. Then the amount of escaping gas to the atmosphere and the costs can be reduced.

3.10 Helium Leakage Test (Accumulation Method)

Leakage testing with helium, basing on the accumulation method is a brand new method, which is offered at the market only since a short time. Therefore, only little practical experience exists.
The method has been designed in a way, that some advantages of other methods could be merged and some previous disadvantages of helium leakage testing could be minimised.

Method:
The specimen is tightened, filled with pressurised test gas and placed under a separating cover. The volume under the cover is swirled continuously to get a homogeneous mixture of the gas, escaping through leaks and the air under the cover. From this mixture a small portion is continuously sucked to the leakage detector, which is able to detect smallest traces of gas.
In the leakage detector a semipermeable silicium membrane is used to increase the helium concentration in a separate detection chamber so, that no extreme vacuum is needed for detection and measurement.
Because of this method, it is possible to measure a increasing concentration.

Test medium: Helium (pure or in arbitrary mixtures with other gases)
Detectable leakage: >0.0001 cm^3/min

Advantages:
- Very small leaks are detectable.
- The test method is easy in its implementation
- With the accumulation method, the increasing of the helium concentration is measured. The influence of natural helium concentration in the atmosphere and the problem of contamination of the background in the working environment are playing a minor role.
- The tests are running in an automatic test bench under fixed conditions according time and pressure. Therefore the test results are independent from the operators concentration and care and better repeatable.

- Temperature and elasticity have no influence to the test result.
- After a scaling of the factor gas concentration / leakage rate, this method supports a quantifiable leakage rate detection.
- The test results can be automatically documented.
- The test cover may be designed simple, is therefore economic and it is not necessary, to have vacuum in it.

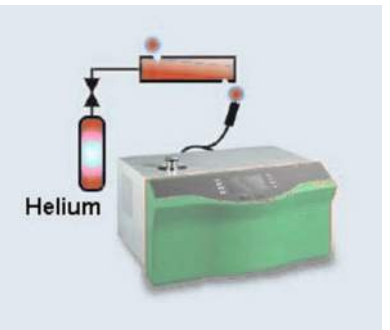
Disadvantages:
- Still remaining risk of contamination of the background in the working environment in case of wrong usage, defects and very rough leaks.
- In case of a contamination, helium causes the biggest problem in cleaning the environment of all tracer gases.
- This method is often not usable for testing plastic parts because some plastic materials have a helium permeability.

Remarks:
- It is absolutely necessary to ensure an accurate and complete filling of the test volume with helium. The test volume therefore should be flushed with the tracer gas or should be first evacuated and then be filled.
- After the test, the tracer gas has to be removed from the working environment in a controlled way. Otherwise there is a risk of rising a background concentration, which could disable the further testing. For that problem helium is the most difficult of all tracer gases.

3.11 Helium Mass Spectrometer Method (Snifting Test)

Method:

For the test helium or a mixture of helium and other gases is filled into the specimen under overpressure. The gas, which is escaping through leakage is detected by a manually operated hand probe.



Illus. 19: Helium snifting unit

The gas mixture at the front of the probe is sucked into a helium mass spectrometer and tested for helium traces.

Test medium: Helium (pure or in arbitrary mixtures with other gases)

Detectable leakage: >0.00001 cm³/min

Advantages:

- Very small leaks are detectable.
- The test method is easy in its implementation.
- Temperature and elasticity have no influence to the test result.
- It is easy to localise the point of leakage with help of the hand probe.

Disadvantages:

- The natural concentration of 5 ppm helium in the atmosphere is a limit for the test.
- This method is often not usable for testing plastic parts because some plastic materials have a helium permeability.
- The tracer gas escapes from the leak as a cloud. The measurement of the gas concentration as a value of the leakage rate depends from the distance between the probe and the point of leak. In manual operation therefore it is impossible to do a quantification of the leakage rate.
- The quality of testing depends to 100% to the operators concentration and care.
- The automatic documentation of the test results is not possible.
- Defined reject part handling is not possible.
- At the test with helium the risk of contamination of the background in the working environment and of the test equipment in case of wrong usage, defects and very rough leaks is the highest of all test gas methods.

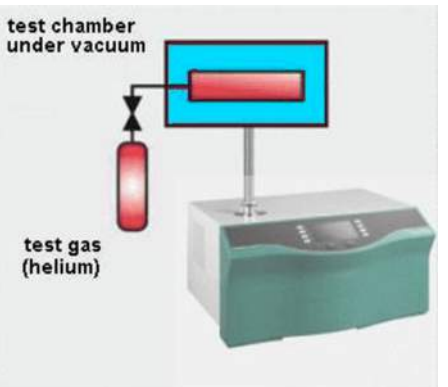
Remarks:

- It is absolutely necessary to ensure an accurate and complete filling of the test volume with helium. The test volume therefore should be first evacuated and then be filled.
- After the test, the tracer gas has to be removed from the working environment in a controlled way. Otherwise there is a risk of rising a background concentration, which could disable the further testing. For that problem helium is the most difficult of all tracer gases.

3.12 Helium Mass Spectrometer Method (Integral Test)

The leakage testing with helium is the eldest, most sensitive and most prevalent method for testing with tracer gas. Many requirements according gas-tight can only be tested with good accuracy if this method is used.
A few years ago the tracer gas detection with help of a mass spectrometer was extremely complex and the instrumentation was very expensive.
Operators and above all service people had to be specifically trained.
Because of continuous improvement of the devices and the rising number of implementations, in the meanwhile a greater number of devices is available, which can be operated without special training. The price of the devices has reduced, even if they are still expensive.

Method:
The specimen is tightened, filled with pressurised test gas and placed under a good fitting hood. The volume under the hood is evacuated in order to disperse traces of test gas, escaping through



Illus. 20: Helium integral test

leaks fast and homogeneously in the whole volume under the hood.
After an accumulation time a sample of the hoods atmosphere is taken and analysed in a mass spectrometer under high vacuum for test gas traces.

Test medium: Helium (pure or in arbitrary mixtures with other gases)
Detectable leakage: $>10^{-10}$ mbar l/s (>0.000000006 cm³/min)

Advantages:
- Extremely small leaks are detectable.
- The test is running in an automatic test bench under fixed conditions according time and pressure. Therefore the test results are independent from the operators concentration and care and better repeatable.
- Temperature and elasticity have no influence to the test result.
- After a scaling of the factor gas concentration / leakage rate, this method supports a quantifiable leakage rate detection.
- The test results can be automatically documented.

Disadvantages:
- Due to the high quality sealing of the specimen under a hood, which itself has to be extremely tight against ambient, this method causes a very high mechanical complexity. An additional effort is generated for diagnostics of problems with the sealing under the hood.
- Not useable for middle and high leakage.

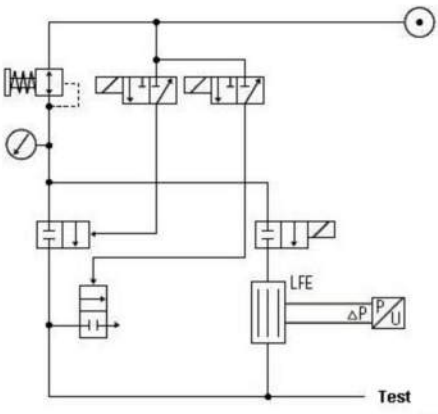
- Very high risk of contamination of the background in the working environment and of the test equipment in case of wrong usage, defects and very rough leaks.
- Costly instrumentation and vacuum technology.
- For the helium detection high vacuum is needed. Therefore the process technology is extremely sensitive against air pollution and moisture.

Remarks:
- It is absolutely necessary to ensure an accurate and complete filling of the test volume with helium. The test volume therefore should be first evacuated and then be filled.
- After the test, the tracer gas has to be removed from the working environment in a controlled way. Otherwise there is a risk of rising a background concentration, which could disable the further testing. For that problem helium is the most difficult of all tracer gases.

3.13 Flow Testing Method (Volume Flow)

The leakage testing according the flow testing method always then is used, if the part has a high admissible leakage rate. This for example is the fact for exhaust gas leading parts behind the catalyser or for parts from ventilation systems. Methods, measuring the pressure or tracer gas methods usually have a too small measurement range.

Method:
The specimen is tightened and filled with a constant air pressure. The amount of air, escaping by leakage, is refilled and measured. At parts with big volume the measurement cell is bypassed during filling. The measurement is done with help of a laminar flow element and a differential pressure sensor.



Illus. 21: Functional diagram Flow testing method (volume flow)

Test medium: Air (mostly only with slight overpressure or vacuum)
Detectable leakage: >100 cm^3/min

Advantages:
- The test is running in an automatic test bench under fixed conditions according time and pressure. Therefore the test results are independent from the operators concentration and care and repeatable.
- The test results can be automatically documented.

- After a scaling of the factor differential pressure / flow rate, this method supports a quantifiable leakage rate detection.
- The method is robust and not sensitive against air pollution and moisture.
- The fixtures can be quite simple.

Disadvantages:
- The scaling is referenced to a defined test pressure. When using a different pressure, a rescaling is required or a recalculation of the measurement value has to be made.
- Measurement ranges below 100 cm^3/min usually are not available.
- Very high temperature changes during the time of measurement can influence the measurement values.
- The measurement range of one single measurement cell, normally only has a range from 1:10 (e.g. 0.1 to 1.0 l/min)

Remarks:
- Primarily during the measurement time a stable regulation of the test pressure is very important.
- The measurement is done as measurement of the differential pressure over a laminar flow element. This means, that the measurement value is mainly defined by the flow speed
- During the usage has to be considered, that the pressurised medium is measured and that flow test devices according the volume flow method normally are scaled for a defined pressure.

3.14 Flow Testing Method (Mass Flow)

The flow testing method, using mass flow sensors, is useable in a wide range of leakage testing. But it has to be realised, that one single sensor only has a range of 1:100 (e.g. 10 cm³/min to 1000 cm³/min). To cover a wider range, devices with more than one measurement ranges and sensors have to be used.
The main field of usage of this method is measuring small and middle leakage. The advantage, using a mass flow sensor is, that the flow rate is measured directly and has not to be recalculated from a pressure change
Measuring the flow with help of a mass flow sensor is independent from the test pressure. So in higher pressure ranges normally mass flow devices are used, although they are more expensive than volume flow devices.

Method:
The specimen is tightened and filled with a constant air pressure. The amount of air, escaping by leakage, is refilled and measured. At parts with big volume the measurement cell is bypassed during filling.
The measurement is done with help of a thermal mass flow sensor.

Test medium:	air, more seldom nitrogen or other gases (overpressure or vacuum)
Detectable leakage:	> 0,1 cm³/min

Advantages:

- The direct measurement of the mass flow allows, sufficient cycle time assumed, the measurement of small and middle leakage also on parts with big volume.
- Due to the test cycle with fixed constant times and monitored pressure, which are defined in the test device, all tests are running under the same repeatable conditions.
- The evaluation is independent from the operator.
- Test units, basing on the mass flow method normally are equipped with interfaces, which allow the integration in an automatic process.
- The test results can be automatically documented, if the device is equipped with a suitable interface.

Disadvantages:

- Measurements according the mass flow method also are effected of any kind of pressure change during the test time. In this case, any small difference of pressure between the test volume on one side and the pressure regulation on the other side of the flow sensor, causes a flow through the sensor.
- Temperature changes during the real measuring time cause a pressure change which influences the flow through the sensor and the test result.
- The pressure change caused by the leakage can be compensated by the elasticity of the specimen partially, then the flow through the sensor is effected.
- Depending on the design of a test device it may be highly sensitive against rough leaks.

Remarks:

- Mainly during the measurement time and with small measurement ranges a very stable pressure regulation is extremely important. Any variation of the pressure, caused by the regulation, will produce a faulty flow through the sensor. The methods, to solve this problem, are often very different from manufacturer to manufacturer.
- The most mass flow sensors are very sensible against over flowing, that means against overshooting the upper limit of the measurement range. This can occur during mistakes in operation or if measured a specimen with rough leakage. Then they loose the fine adjustment for a short time and do not fit the specifications any more.

3.15 Special Methods

3.15.1 Modifications of the Mentioned Methods

Nearly all described methods can be modified in the way of usage, if required. So a test better can meet the real usage conditions of a specimen, can be easier or economic, or can be possible at all.

Such modification for example can be:

The “pressure build-up method”, that means at the indirect measurement of a leakage under a hood, of course also can be done with high overpressure under the hood if the part under real conditions is exposed to high pressure from the outside. The measurement then takes place in the inner of the specimen.

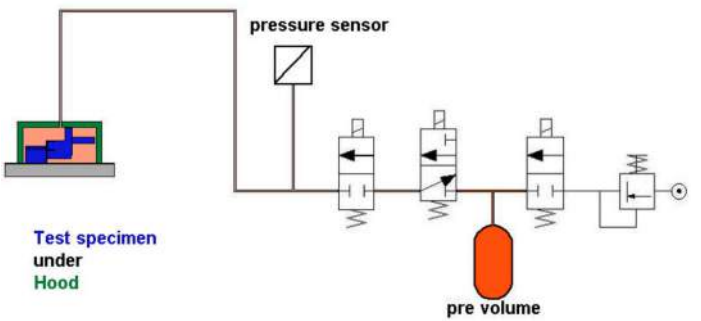
Using any snifting method with a tracer gas, also can be done by placing the probe inside a hood or a cover in which the gas, escaping from the specimen, is swirled with the surrounding air.
Integral working tracer gas methods, which usually measure the mixture surrounding the specimen, of course also can measure inside of an evacuated specimen if the tracer gas is filled into the surrounding hood.
In this case the tracer gas also can be sprayed to critical positions from the outside.

3.15.2 Testing of Hermetically Sealed Parts

All until now described methods require, that the inner volume of the specimen is reachable.
But more and more parts are hermetically sealed, because they are used outdoor and for example are exposed to the weather conditions at the outside of a car.
Parts like this are also tested under a hood. In the serial production, during testing watertightness, pressure measuring methods are used. These however have to be modified for that case.

Method:
The specimen is put into a test chamber, which is hermetically sealed against surrounding. The remaining volume in this chamber is filled with overpressure or evacuated. Then the pressure change, which only can be reasoned by a leakage in the specimen, is measured as a proportion of the leakage and valued.
This can be done either according the relative pressure method, like shown in Illus. 22, or according the difference pressure method.

The filling although has to be done divergent to the usual methods with a defined amount of air, otherwise it is not possible to detect rough leakage.
First of all, the pre volume is filled with a pressure, higher the test pressure. Then this volume is blocked against the pressure regulation and the pressure is expanded into the chamber.



Illus. 22:
Testing of hermetically sealed parts (basic diagram showing relative-pressure implementation)

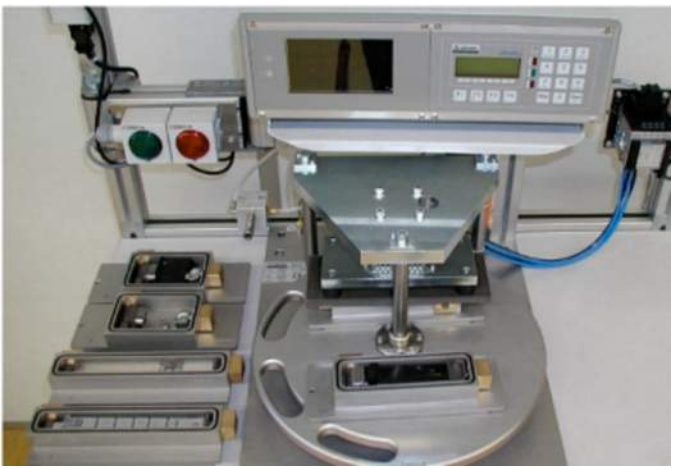
Depending on whether the inner of the specimen is filled because a rough leakage or if it is basically tight, the filled volumes are different and a different pressure is reached. This pressure is monitored and used for detection of a rough leak.

Test medium: air, more seldom nitrogen or other gases (overpressure or vacuum)

Detectable leakage: > 0,1 cm^3/min (depending on method, volume and test pressure)

Remarks:

- The volume, filled by the specimen may vary by some percents because of the dimensional tolerances of the part. This is why during design of a test bench according the described method should be ensured that the inner of the specimen has at least 5% of the complete test volume. Otherwise, the limit value for rough leaks will be too close at test pressure.



Illus. 23:
Manual working station for testing of hermetically sealed parts with interchange parts for different types of specimen

- If a test bench is designed like shown in Illus. 22, the test pressure regulation has to be long time stable, because variations of the test pressure have an influence to the rough leak detection.
  Especially for testing specimen with small inner volume, it is useful to design a higher level test with more measurement points.

3.15.3 Cambering

If hermetically sealed parts have to be tested with help of a tracer gas method, there must be found a method to fill them with the gas.
Normally this is only possible at untight parts.
The specimen for that are placed into a chamber, which is evacuated. At untight parts, the inner volume will be evacuated by this. After a waiting time, the chamber is filled with the tracer gas, which can permeate into the before evacuated untight samples.
After a next waiting time the specimen are tested under a cover or under a hood with one of the described gas detection methods. Because it was not possible for the test gas to permeate into tight parts, these will be classified as "good".
Untight parts, which are filled with gas can be detected easy.

Remarks:

- If a specimen is roughly untight, there is a risk, that the gas escapes after cambering but before testing.
- This method is very time-consuming and requires a high accurateness during execution. For this reason it

is rather not usable for a 100% test in the large-volume production.

3.16 Combined Tests

Often at one specimen have to be performed more than one test. This for example is the fact at cast parts from the automotive industry, which include circuits for air, oil and water. In this case more than one leakage test can be done in parallel, as far as the circuits do not contact. If neighbouring circuits have to be tested against leakage to the environment and against each other, so different test pressures have to be used.
The lower pressure then has to be monitored against rising and falling pressure.
If such a test has to be carried out with a tracer gas method, the circuits have to be tested sequential, one after the other.

Tests, where a leakage test is combined with other fluidic tests, for example a flow or flow resistance test, usually require the design of a product specific test circuit. They only should be designed by a specialist with high experience.

4 SELECTION CRITERIA

To take a choice, which test method is most suitable for a special task, the following aspects have to be considered, which will be highlighted in detail in following chapters:

- Leakage rate
- Characteristics of the specimen
- Characteristics of the production
- Operating conditions of the specimen
- Costs of testing
- Required quality assessments

4.1 Leakage Rate

An overview of the methods, which are suitable for a defined or self fixed leakage rate is shown in the diagram in Illustration 7.

To test bigger leakage rates (>10 cm^3/min) the probably oldest method of air-under-water-testing is useable as well as the pressure measuring methods and the flow measuring methods. If a big admissible leakage rate has to be measured exactly, to use the allowed tolerance completely, tests according the flow test methods are to be preferred.

In the range of middle until small leakage (0,1 cm^3/min to 10 cm^3/min) the most leakage tests are working. This is the range of all kinds of liquid tightness and it is possible to use nearly all known leakage test methods.
Here more decision criteria have to be considered.

The range of small until very small leakage rates (<0,1 cm³/min), apart from a few exceptions, can only be covered by tracer gas verification methods. Here also are additional considerations necessary to find the best fitting method.

4.2 Characteristics of the Specimen

In the following some possible characteristics of the specimen shall be listed, which require special actions for some test methods or even make them impossible.
The list cannot and will not be complete. It only shall give some indications, which characteristics require special notice.

4.2.1 Flexible Parts

As already mentioned in the descriptions of the different methods, tests of all flexible parts with pressure depending methods may cause problems.
For testing of flexible parts, gas verification methods have clear advantages.

The more economic methods of pressure or flow measurement often can be used anyhow, if some facts are considered.
For example, elastic elements in a specimen, like a membrane can be supported by the fixture, as long as no possible point of leakage is sealed by the support.
Another possibility to reduce the elastic effects is to “overfill” the specimen. Thereby during a short time at the beginning of the filling step the pressure is raised approximately 5-20% over the test pressure. then it is reduced

before the filling is ended. This normally makes the test more stable.

4.2.2 Parts with Big Volume

Parts with big volume may be difficult to test with the relative pressure or the difference pressure method.
If this test methods are possible, can be decided by calculation the pressure change basing on the estimated volume and the required limit.
The pressure change, which is caused by the limit flow should be 20 times at the relative pressure method and 50 times at the difference pressure method higher than the resolution of the measurement.
This calculation can be done with help of the following formula.

$$\Delta p = \frac{Q_{leak} * t_{test} * 1{,}013\ mbar}{V_{test}}$$

where

Q_{leak} is the limit,

V_{test} is the estimated complete volume of specimen, fixture, tubes and test unit and

t_{test} is the available time for measurement (test time of the unit)

4.2.3 Difficulties during Filling and Emptying

Gas detection methods reach their limits from technical view always then, if the complete filling of the test volume with the tracer gas can not be guaranteed.

This for example is the case, if the specimen is not stable enough to evacuate it for filling and at the same time has areas, which can not be flushed.
One more critical point for a gas detection method can be, if the specimen after the test can not be emptied really clean. Then from already tested parts, stored at the working place, gas can diffuse out and contaminate the working environment in a way, that further testing may be disabled.

An other type of parts, which are difficult to fill and empty, are parts, which are made of or include sinter materials, charcoal or other open-pored materials. In pressure or flow measuring tests they need extremely long filling and stabilisation times to fill all the pores. And even then it may happen that the measurement value becomes smaller from test to test while repeated testing of the same item. If a break of some minutes is made during testing, the start value will be reached again.
If those parts are tested with any gas verification method, the risk of contamination of the working environment with outgassing tested parts is very high.

4.2.4 High Heat Conducting Materials

Parts, which are made of high heat conducting materials, or are optimised to good heat conduction because of their future usage, for example like coolers, require special diligence in designing a test bench. If it is planned to test them according the relative pressure, the difference pressure or the flow test method, special provisions have to be planned, to reduce physical, especially thermal effects during the measurement time. For more details see later chapters.

Also for those specimen a gas detection method would be suitable, if this is possible by all other reasons, especially for economic ones.

4.2.5 Hermetically Sealed Parts

As already mentioned, these types of specimen only can be tested according the both described methods.

4.3 Characteristics of the Production

The production characteristics have great importance for the selection of a suitable test. The most important criteria will be examined below.

4.3.1 Automation Level

Usually the production of industrial goods today is carried out with high automatisation level and with consciously reduction of the possibility of human intervention. By this a constant production quality is realised.
On the other hand, this at the same time excludes all these test methods, in which the operator is responsible for the evaluation of the quality (air-under-water-method, bubbling through method) or in which he has a drastic influence to the quality of the operation of the test, like in operating the snifting methods. But this also means, that manual test methods have a higher importance if the tests have to be done at a smaller number of parts.
For single parts, in small series or if only samples have to be tested, the usage for a semi- or fully-automated solution may be too costly. In this case, inspection instructions and substantial training of the operator is strictly recommended.

4.3.2 Cycle Time

The level of automation is closely connected with the cycle time.
Especially at short cycle times sometimes a bit more effort has to be invested into a test bench to reach this cycle time with one station and save a second.
So a test according the pressure build-up method can be realised during testing with high pressure in a much shorter time, than with a direct measurement according the relative or difference pressure method.
In this case, the higher invest for a more complex test station is profitable for cycle time reduction.
On the other side it of course makes no sense, if enough cycle time is available.
Testing according the gas detection methods normally need some more time than pressure of flow measuring methods because they include a lot of single steps in the test cycle. If possible by all other reasons pressure or flow measuring methods should be preferred for a short cycle time.

4.3.3 Temperature Conditions

For selecting the method of test, the temperature conditions probably have the most importance.
Usual for middle and small leakage in industrial area the pressure or flow measuring methods are preferred because of simplicity and economy.
Special temperature conditions however may be a clear criterion for the exclusion of these methods because the temperature profile during the test has an immense influence to the test result.

The temperature profile depends on the temperature of the used air, the temperature of the specimen and the ambient temperature.
If the temperature of the air in the test volume during the test rises, for example because of a warm specimen or because of cold air, the pressure also rises. A pressure drop, caused by a leakage may be equalised, by what a untight part will be classified a “good”.
If the temperature during the test drops, for example caused by cold airflow, the pressure also will decline. A pressure drop, caused by a leakage thereby may be amplified in a way, that a real tight part is classified as “bad”.

How high the influence of the temperature to the test value is, shall be shown with help of the following example.

Test pressure:	1,000 mbar relative overpressure (p = 2,013 mbar abs.)
Test volume:	V = 110 cm³
Admissible Leakage rate:	Q = 0.5 cm³/min
Measurement time:	5 sec
Temperature of the air, used for testing:	t = 23°C, changing to t = 23.1°C

The pressure change, basing on the leakage rate is calculated with help of the following formula:

$$\Delta p_{leak} = \frac{Q_{leak} * t_{test} * 1{,}013 mbar}{V_{test}}$$

in our example

$$\Delta p_{leak} = \frac{-0.5\ cm^3/min * 5s * 1{,}013mbar}{110\ cm^3 * 60\ s/min}$$

$$\mathbf{\Delta p_{leak} = -0.38\ mbar}$$

The pressure change Δp_T basing on the change of temperature is calculated by approximation basing on the following formula:

$p \times V = R \times T$ with V = const.; R = const.

$\frac{p_2}{p_1} = \frac{T_2}{T_1}$ with $T_2 > T_1$ (t°C + 273 K)
p = absolute pressure

$\Delta p_T = p_{T2} - p_{T1}$ $\quad p_{T2} = p_{T1} \times \frac{T_2}{T_1}$

$\Delta p_T = p_{T1} \times \frac{T_2}{T_1} - p_{T1}$

Due to a temperature change from 23.0 to 23.1°C during the test time, the following calculation has to be done:

$$\Delta p_T = 2013\ mbar \times \frac{295.1\ K}{295.0\ K} - 2013\ mbar$$

$$\mathbf{\Delta p_T = +0.68\ mbar}$$

In our example the pressure will rise by 0.3 mbar, caused by temperature, although the part has a leak with 0.5 cm³/min.

$\Delta p = \Delta p_{leak} + \Delta p_T = -0.38\ mbar + 0.68\ mbar = \underline{+0.3\ mbar}$

If for this test a pressure or flow measuring method shall be used, greatest importance has to be attached to minimise the influence of the temperature.

However the influence of the temperature also may not be overstated. A temperature rising like shown in the above example from 0.1 degree during 5 s will occur only under extreme conditions.
Because air is a bad conductor of heat, usually only a small surface layer will be warmed up and the average of air temperature only will rise by a small amount.

4.3.4 Test Pressure

Like mentioned before, the temperature change during the measurement has a relevant influence to all methods, which measure pressure or flow. Under this viewpoint also has to be examined the test pressure.
During the filling a heavy pressure drop at the filling valve is generated, which causes a cooling down of the air. Only short time later, at the end of filling, the air is compressed again, which causes a warming up of the air.
Especially at parts made of high warmth conducting material, the wall of the specimen is influenced by this temperature changes and is either warmed up or cooled down. Which of both temperature effects is outbalancing, depends on the volume and the streaming conditions during the filling. This can practically not be forecasted.
Fact is, that already beginning with some bar overpressure this effects are disturbing the stability of the test results. Then longer stabilisation times are required. With a test pressure of or above 10 bar, a direct measurement of pres-

sure or flow should not be used and instead of this, a indirect measurement under a hood or a gas detection method should be preferred.

4.3.5 Leakage Localisation

If manufacturing high-grade components, it often makes sense to repair faulty parts. For faulty parts from leakage testing this means, that the point of leak must be known. So a method has to be used which enables the localisation of the leak.
Because these methods can not be recommended for large-volume production, a compromise has to be found:
Here often is established, to do the standard test with an automatic device and a method, which works without operator influence. Only faulty parts are then tested with a localising method during the repair.
With low number of pieces and low automation level the direct usage of a localising method can be recommended.

4.3.6 Influence of Ambiance

Under this general term all events in the production environment can be summarised, which can effect the test process.
The gravest example is a process near a tracer gas test equipment which releases the used test gas and with that, rises the background concentration of this gas to an unacceptable height.
But the influence of ambiance can also effect a pressure or flow measuring device that is placed directly beside a hall door, which is opened at all outside temperatures. A similar effect can have the sun, which sometimes shines to the

test position through a window or a rooflight and rises the temperature of the specimen during the test.
Another critical point is the variation of the pneumatic pressure at a test bench, because it can influence the force of clamping and sealing movements and can be the reason for unrepeatable test results.
Unsteady consumption of pneumatic air in the surrounding of pressure or flow measuring test devices may be a reason for a variation of the temperature of the compressed air, which is used for the test and then may be the reason for variations in the test results.
Also variations in temperature and non-repeatabilities are caused by specimen, which are stocked outdoor and brought to the test device shortly before the test.
If those parts also are moistly or even wet, all methods, working with vacuum are highly influenced. During evacuation the moisture vaporises very fast and a smaller vacuum is reached during the evacuation phase.
At gas detection methods, basic parameters like fill factor, the gas mixture inside of the test volume and the dispersion of the tracer gas are constrained.
In the worst case, at the measurement of a reject part, the limit value is just not reached and the part will be classified as “good”.

4.4 Operating Conditions of the Specimen

The test conditions of a specimen should be as near as possible at the conditions of usage of this part. Therefore, the operating condition may be determinant for the chosen test method.
Components, which have to withstand to a high pressure from the outside, should also be tested in this way. So,

they have to be tested in a hood with high pressure under the hood and measured in the inner of the specimen.
Other imaginable usage conditions, which can effect the method of testing are mechanical loads, which have to be emulated in the test station or included functional tests, which could effect the temperature, e.g. the switching of motors or illuminations.

4.5 Costs of Testing

The costs of testing include some separate cost blocks. They are composed of

- costs per test,
- invest of the test equipment,
- cost for the part specific fixture,
- personnel expenditures,
- costs for service and maintenance,
- costs for periodically function checks.

The costs per test mainly are determined by the used test medium. Here pressurised air, surely is substantial cheaper than the different tracer gases.

Also for the costs of invest clearly can be stated, that these for a pressure or flow measuring device will be considerably lower than for a gas detection device. For these, except for the expensive sensor system, also the costs for test gas handling has to be budgeted.

The costs for part specific fixtures always then rise very high, if the test has to be done under a hood.

The personnel expenditures depend on one side from the fact, if an operator has to stay all the time at the test equipment, on the other side from his qualification. In this case of course automatic test equipment has to be preferred.

At costs for service and maintenance thoughts are helpful, if the manufacturer of the test device for that work has to send and charge a technician or a graduate engineer. Furthermore the consideration of spare parts costs is useful.
If the manufacturer offers a possibility of telemaintenance, which can bring cost-saving immediate help during sudden testing problems, this is a clear advantage.
Also at this block of costs, the more simple and robust methods, measuring pressure of flow have an advantage.

The expenses for periodically function checks have to be added. They consist of costs for facilities, costs for the time needed for the check and costs for frequent calibration.
Here also the more simple systems, working with air, have slight advantages.

4.6 Required Quality Assessments

The last point, which influences the choice of the test method, is the question of the required quality assessments to be provided.
Hereby it is an essential decision criterion, if a classification by the operator or a significant influence of the operator is accepted. If not, all manual methods have to be dropped out.

Furthermore it has to be checked, if test results and / or measurement values have to be documented and if yes, in which extensiveness. If this is possible with the favoured method has to cleared with the manufacturer of the test device.

5 DESIGN ADVICE FOR TEST BENCHES

The design of the test benches and the specific clamping and sealing fixture has an essential influence to the quality and long-term stability of a leakage test. The following chapters shall give some advises for a suitable design with the focus to leakage testing.

5.1 Basic Structure

The attention of some simple principles helps to realise pre-conditions for repeatable test as well for pressure or flow measuring methods as for gas detection methods.
Pressure of flow measuring test devices have to be shielded against temperature influence best possible.
Thereby it is an advantage, if the working area of the test bench during the test is protected against airflow by a closed safety guard from all sides. Meeting the safety requirements of a semi automatic test bench by a light grid at the operators side can not perform this.
The top side of the test bench should be protected against direct solar radiation by using a light-tight cover.
A good temperature adaptation of the test air can be reached in simple way, if a long (>20 m) tube is used to connect the test equipment with the air supply. Because test equipment normally has no big air consumption, the durance of stay of the air in this tube is long enough to reach a good temperature adaptation.

Test benches, working according any tracer gas method, also should be completely covered. The task of this housing however is, to avoid the mixture of small gas traces,

which may escape during opening a fixture with the surrounding working environment.
Additionally this housing permanently should be cleared with help of a ventilation system. This exhaust air as well as all air generated during the test, have to be passed into a factory aeration system to bring it outside and far away from the test equipment.

5.2 Clamping Movements

In principle is valid, that the specimen shall be loaded in the fixture in that way, that equates to their later application.
That means, that the clamping forces, necessary to the specimen in the fixture, if any possible should act on screwing positions or other points of attachment. (Illus. 24). If this is not possible, at least carefully should made sure, that areas to be tested (e.g. weldseams at housings, screwed top covers with sealing function etc.) never are compressed by the clamping force.
Clamping movements have to equipped with enough functionality to equalise the tolerances and variations of the production.

5.3 Test Fixtures

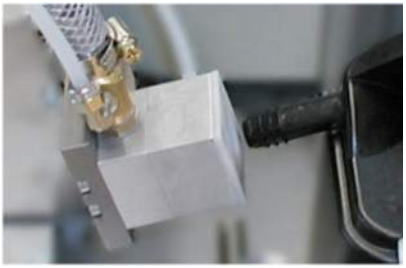
Test fixtures have to be equipped with filler element if parts are tested, which have a wide opening.
The reduction of the test volume increases the measurement sensitive in pressure measuring devices and reduces the consumption costs in gas detection devices. But it has to be ensured, that at the filler element or its attachment

points no voids are generated, in which air or tracer gas slowly can flow in or flow out.
Otherwise pseudo leaks are produced or the contamination of the of the background in the working environment during standstill of the equipment is caused.
All fixtures at manually loaded test benches have to be provided with guiding to enable a repeatable positioning of the specimen. (Illus. 26)

Illus. 24:
Fixture for a cylinder head cover with filler element and holding down plunger acting on the screwing positions

5.4 Sealing and Sealing Movements

The sealing of the specimen during test also should be in best possible accordance with the later sealing during use.
Tube connectors have to be clasped around, mounting surfaces of housings to be sealed with shaped gaskets basing on the originals but are more wear-resistant, at future o-ring seal faces, o-rings should be used for testing etc.



Illus. 25:
Tube connector sealing

The beside example (Illus. 25) shows the sealing of a tube connector with help of a from outside attached inflatable sealing sleeve. With this method, also damaged sealing edges which would cause problems in the later application can be found without any difficulty.

Another example (Illus. 26) is the use of a shaped gasket for a mounting surface, which is designed according the original but manufactured out of a material which has only little abrasion and is flexible over a long time. So the permanent change of the specimen will not cause abrasive wear.

Illus. 26:
Fixture with guiding and a shaped gasket

In this case, instead of the also possible and much simpler flat sealing the

shaped gasket was chosen, because with this, damages of the seal face can be found, if they are located at the contact surface of the serial gasket.

Illus. 27:
Sealing from the front with support of the specimen with help of the fixture

Like the clamping movement also the sealing movement must not have any effect, which could influence the tightness functionality of the specimen. This at critical specimen can be reached by interaction of a support in the fixture which can hold the force of the sealing device or with help of a special design of the sealing device which produces a closed distribution of forces at the point of sealing.

Illus. 28:
Manual sealing units with closed distribution of forces

Compressible sealing, which can be carried out in nearly each outline are also very reasonable. They are

moved expanded without any force to the position of sealing and then are compressed in longitudinal direction. By that, their profile is changing, the sealing contacts the surface of the specimen and the original movement can be switched forceless.

Sealing movements have to equipped with functionality to equalise the tolerances and variations of the production.
Gaskets have to be used in a way, that the abrasion is not too high and that they can be changed easily.

In general it must be ensured, that sealing movements can not move during test in any way. This normally is reached by a movement which is stopped by a fixed support at the fixture or at the specimen. In this stop position the sealing device has to compress the gasket and has to have power reserve.

The following sample calculation shall demonstrate how important is a stable sealing situation:

The part from the example in chapter 4.3.3 “Temperature Conditions” may have an connecting tube with diameter 30 mm which is tightened with a flat gasket without fixed support.
Its volume is 110 cm^3, the admissible leakage rate 0.5 cm^3/min and the test pressure 1 bar relative overpressure.

During the test sometimes there will occur a small movement of 0.2 mm because of a friction in the pneumatic device and the gasket is compressed a bit more, so that it

is pressed 0.2 mm deeper inside the part. Thereby the volume is reduced from 110 cm³ to 109.859 cm³.
The original test pressure of 1 bar relative overpressure (2013 mbar absolute) is changed as follows:

$p_2 = p_1 \times V_1 / V_2$
$p_2 = 2{,}013 \text{ mbar} \times 110 \text{ cm}^3 / 109.859 \text{ cm}^3$
$P_2 = 2{,}015.584 \text{ mbar}$

The pressure in the specimen rises because of the faulty sealing method by 2.584 mbar and disables the detection of the leakage of 0.5 cm³/min, which causes a pressure drop of -0.378 mbar.

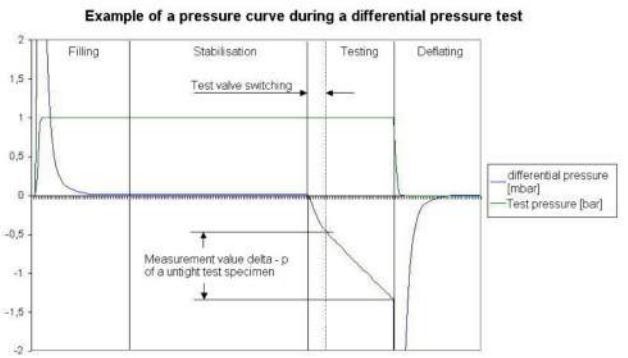
5.5 Test Chambers and Hoods

Test hoods for the pressure build-up method, all gas detection methods and for special test methods have to be built in a way that the dead volume is reduced as much as possible.
At pressure measuring methods thereby the sensitivity is increased and at tracer gas methods a higher test gas concentration in the hood is reached.
For gas detection methods, where the atmosphere in the cover is swirled, a compromise has to be found. In spite of a small volume, a good swirling must be possible. The streaming areas must not be too small.

At pressure measuring methods, it is extremely important, that the hood is moved with power reserve to a fixed stopper, so it can not move during the test.

6 ADJUSTMENT INFORMATION FOR PRESSURE TESTING METHODS

In the chapters before, at many points was mentioned, how physical conditions can disturb the test quality of pressure measuring test equipment. Because pressure measuring mostly is the best suitable and economic method, below some advises shall be given, how the influence of external disturbing effects can be reduced by optimising the test parameters.
For that purpose as an example the pressure / time chart of a difference pressure test shall be explained.



Illus. 29:
Pressure / time chart of a difference pressure test

The test cycle is controlled by the four main steps “filling“, “stabilisation”,” testing” and “deflating”, which are time adjustable and by the “test valve switching” time, which usually is a test device parameter.

In the step filling the test volume and the reference volume are filled. In the step stabilisation, the turbulence, caused by the filling shall abate. Also a temperature balancing between specimen and test air shall occur.
At the beginning of the test time the pressure signal from the difference pressure sensor is measured and mathematical set to zero. Now only the signal of this sensor is monitored. At the end of the testing the calculated difference between beginning and end is rated.
During deflating the test volume is brought back to ambient pressure.
Between stabilisation and testing in the before diagram the step “test valve switching” is visible. This is an additional device specific stabilisation time, during this a pressure impulse, caused by the test valve shall die away.
The start of the measurement happens at the end of test valve switching time.
In general, at adjustment of the step times, the complete available cycle time should be used because global can be stated:
As longer the cycle time of a test as better is the repeatability of the test results.

For the splitting of the cycle time to the different steps, the following basic knowledge may be helpful.

The length of the test valve switching time is responsible for the influence of the valve switching impulse to the test value. If during the observance of the difference pressure values at the beginning of the test time a fast pressure

change is viewable than at a later time, the valve switching impulse does not completely abate.
While measuring completely tight specimen, you always will have a “basic” measurement value, which is different from zero. Lengthening of the test valve switching time, if possible, will abate the system better and the result will be a more real measurement value.

The durance of the testing time influences during a real pressure measurement, that means without recalculation to a pressure decay per time, the height of the measurement value.
Because at the same time all outside disturbing effects are directly measured, from this side of the view, the testing time should be as short as possible.
The perfect compromise then is found, if the measuring value at the limit for relative pressure measuring is at least 20 times, for difference pressure measuring at least 50 times of the measurement resolution.

The time for deflating can be adjusted short. It is sufficient when sibilance can not be heart during opening the fixture. The final pressure drop then is the result from opening the fixture.

The remaining time has to be used for filling and stabilisation time. As longer these times are, as better repeatability the measurement will have.
The filling time is long enough, if at the beginning of the stabilisation time no significant pressure change is viewable.

In the meanwhile some leakage test devices are equipped with a software package, which includes this knowledge and is able to adjust the times in a optimised way by analysing the pressure profile.

7 RATING OF THE TEST QUALITY

To evaluate the test quality of a leakage test device, usually the capability of the test unit or test circuit and of the complete test bench is calculated.
It is very important that this evaluation is done with the same parameters, which are used for serial testing.

For calculation the gauge capability c_g only the gauge, that means the leakage testing device or the leakage testing circle in a machine is evaluated. Effects of the specimen or the fixture stay unconsidered.

Ideally 25 or better 50 measurements with one well known tight specimen are carried out without opening the fixture and touching the specimen.
Depending to the specimen, it may make sense to wait one or two minutes between the measurements.
In a second test series in the same way the same part is measured together with a test leak, which has the value of the limit.

The arithmetic mean of both test series represent the lower and the upper limits.
The gauge capability c_g is calculated as follows:

$$c_g = \frac{0{,}2*T}{6*\sigma} = \frac{0{,}2*(\left| x_{\text{mean leak}} - x_{\text{mean tight}} \right|)}{6*\sigma}$$

with

σ = standard deviation of the test cycle
T = field of tolerance
$x_{\text{mean leak}}$ = arithmetic mean of the test cycle with test leak
$x_{\text{mean tight}}$ = arithmetic mean of the test cycle without test leak

This calculation can be done without any scaling of the device to a leakage rate.
If no test leak is available, before the run of the test series, the gauge has to be scaled to the unit, in which the admissible leakage rate is defined.
In this case, only the test series with the tight part has to be performed.

The field of tolerance in this case is defined:
smallest value = 0
maximum value = limit value

For that case the formula looks as follows:

$$c_g = \frac{0{,}2*T}{6*\sigma} = \frac{0{,}2*\left|\text{limit value} - 0\right|}{6*\sigma}$$

If the test series with the tight part gives a mean, which is different from zero, the calculation of critical capability C_{gk} has to be performed according the following formula:

$$c_{gk} = \frac{0{,}1*(\left|\text{limit value} - 0\right| - \left|x_{\text{mean tight}}\right|)}{3*\sigma}$$

The index of capability has to be better than 1.33, better than 1.67 or better than 2.0, depending on the quality requirements of the company.

As soon as the capability of the measuring system is verified, in the same way the capability of the machine, that means in this case of the test bench, has to be checked. Here the repeatability of the fixture, its capability to compensate mechanical tolerances and all other, perhaps influencing devices are included.

For that 25 or 50 well known tight parts have to be available, which are from the mechanic side in the range of normal production. The test series now are performed with changing the parts. Each part is loaded to the machine, tested and unloaded.
If a test leak available, the test series has to be repeated with test leak.

For the capability of the test bench (machine) is valid:

if working with test leak:

$$c_m = \frac{T}{6*\sigma} = \frac{\left| x_{\text{mean leak}} - x_{\text{mean tight}} \right|}{6*\sigma}$$

if working with limit:

$$c_m = \frac{T}{6*\sigma} = \frac{\left| \text{limit value - 0} \right|}{6*\sigma}$$

and for critical machine capability:

$$c_{mk} = \frac{0{,}5*(\,|\,\text{limit value} - 0\,| - |\,x_{\text{mean tight}}\,|)}{3*\sigma}$$

Here also the index of capability has to be better than 1.33, better than 1.67 or better than 2.0, depending on the quality requirements of the company.

8 PERIODICAL INSPECTION

The periodical inspection of a leakage test device has the purpose to ensure a repeatable quality of the test. It should be performed at the both following levels:
Level 1: a periodical plausibility check with the target to check the fundamental functional capability and to recognise defects, which may have occurred.
Level 2: a preventive maintenance with calibration and scaling if required, with the target to ensure a long time functional capability and the quality of the measurements.
Fortunately the most happen defects, worn gaskets at the test adapters, generate an increased rate of rejects and will be identified without additional measures.

8.1 Frequency

The frequency of the plausibility check depends on the modality of delivery of the tested product. It should be chosen in a way that the delivery of the production charge between the last and the actual plausibility check can be stopped, if a fault is detected.

The frequency of preventive maintenance and calibration depends on the operational conditions and has to be defined by the user, together with the manufacturer of the test equipment. A frequency of one time a year has shaped up as a good average, but there are a lot of test devices where this frequency should be shorter:

- Systems, where because of the test method and the environment conditions dirt, oil or moisture can pollute the measurement system.

- Systems, which are used to test plastic parts, made of glass fibre reinforced materials. The free glass fibres cause a very high abrasion in the valves, which are involved in the test process.
- Systems, which are exposed to high stress from the production environment.

8.2 Plausibility Check - Procedure and Facilities

The plausibility check has to be planned in a way, that it can performed by the operator himself without additional functional assistance.
Convenient is to perform it at the beginning of production, which would cause a frequency of one time per shift. This should be adequate in the majority of cases.

Illus. 30: Test leak

As a tool a well-known tight part is used, which one time is tested without and a second time together with a test leak or another leakage equivalent at or near by the limit value.

In that way, two measurement values in the area of the limits of the used measurement range are generated, which both have to be documented. The variation over all performed checks must not be more than 5%, otherwise the reason has to be detected.
Depending on the automation level of the test equipment, the plausibility check and the documentation has to be performed manually by the operator or is running automatically.
As a leakage equivalent in the most cases a inexpensive test leak can be used, which is produced out of a capillary tube and has a fixed value.
Using adjustable test leaks causes risks of maloperation.
Extremely small leakage, how they occur mostly in gas detection test equipment, can not be produced as capillary tubes.
Instead of this, the manufacturers of gas detection systems offer some methods, which help to bring smallest amounts of tracer gas to the test circuit to generate a concentration which equals a small leakage.
If special designed test methods and procedures are used, the plan for the frequent plausibility check should be discussed with the manufacturer and needed facilities should be ordered in time.

8.3 Preventive Maintenance and Calibration

The plan for preventive maintenance periods and the definition, which parts thereby have to be checked for wear, should be designed by the manufacturer of the test equipment.

It is also reasonable, if the manufacturer of the test equipment does the preventive maintenance, because then the risk of unplanned non-operation periods is smaller.
Often there is also a risk, that due to mistakes during preventive maintenance the functional capability will be lost, if it is done by the user.

Calibration strictly has to be done after the preventive maintenance. It includes the check of all functions, which are relevant for the test task and the documentation of all measurement values with must and measured value.
It is strictly recommended, that also this work is done by trained specialists of the manufacturer to avoid unplanned non-operation periods.
A calibration at the place of operation has to be preferred, because then there is no risk of transportation and the non-operation times again will be shorter.

Calibrations always have to be performed with measurement unit, which is traceable to national or international standards and have to be documented.
In case of a unallowable high deviation, the user has to decide, how far the detected mistake effects the quality of the already delivered products. Then he has to take appropriate action.

Too high deviations of the measurement values normally can be corrected by the manufacturer by a rescaling of the sensor.

If any problem is found during a calibration, the reason has to be identified and the frequency of calibration has to be reconsidered critically and if necessary changed.

9 APPENDIX:

Recalculation of Leakage Rate Units

	cm³/min ml/min	l/min	mbar l / s	Pa m³ / s
1 cm³/min 1 ml/min	1	0.001	0.0167	0.00167
1 l/min	1,000	1	16.667	1.667
1 mbar l / s	60	0.060	1	0.1
1 Pa m³ / s	6	0.006	10	1

Admissible Leakage Rates

characteristic	admissible air leakage rate	
	from	to
waterproof	0.5 cm³/min	12 cm³/min
oil-tight	0.6 cm³/min	4.5 cm³/min
fuel-tight	0.0006 cm³/min	3.0 cm³/min
gas-tight	has to be deduced from the usage	

IP-Protection Classes

Protection Class	Protection against	Ancillary Conditions
IPX1	dripping water	vertical
IPX2	dripping water	± 15° from vertical
IPX3	spraying water	with 10 l/min ± 60° from vertical
IPX4	splash water	10 l/min from all directions
IPX5	jet of water	jet of 12,5 l/min from all directions
IPX6	heavy jet of water	heavy jet of 100 l/min from all directions
IPX7	temporarily immersion	depth: 1000 mm, durance: 30 min
IPX8	longer immersion	according demand of the customer

Additionally, there exists for the automotive area:

IPX4k – protection against splash water from all sides with higher pressure.

IPX6k – protection against heavy jet of water with higher pressure.

IPX9k – protection against water during high-pressure or steam cleaning.

Dynamic Viscosity

dynamic viscosity η [mPa*s]			
Gases		Liquids	
Helium	0.0186	Benzol	0.601
Air	0.0171	Lacquer	approx. 100
Sulphur hexafluoride	0.0156	Motor oil (at 100°C)	approx. 6 - 7
Hydrogen	0.0084	Water	1.000

Surface Tension

liquid	surface tension
benzol	28,90 x 10^{-3} N/m
silicon oil	18,50 x 10^{-3} N/m
water	72,75 x 10^{-3} N/m

Conversation Between Flowrate and Pressure Decay

$$Q_{leak} = \frac{V_{test} * \Delta p}{t_{test} * 1{,}013\text{mbar}}$$

$$\Delta p = \frac{Q_{leak} * t_{test} * 1{,}013\text{mbar}}{V_{test}}$$

with
Q_{leak} = leakage flow
V_{test} = test volume
Δp = pressure change during test time
t_{test} = test time

Conversion from a pv-value to a flowrate

Under production conditions it is approximately:

1 mbar l/s= 1 cm³/s = 60 cm³/min

Conversation of Pressure Units

	bar	mbar hPa	Pa N/m²	at kp/cm² kgf/cm²	atm	mmWS	Torr mmHg	psi lb/sqi
1 bar	1	1,000	100,000	1.02	0.987	10,200	750	14.5
1 mbar 1 hPa	0.001	1	100	0.00102	0.000987	10.2	0.75	0.0145
1 Pa 1 N/m²	0.00001	0.01	1	0.0000102	0.00000987	0.102	0.0075	0.000145
1 at 1 kp/cm² 1 kgf/cm²	0.981	981	98,100	1	0.968	10,000	736	14.22
1 atm	1.013	1,013	101,300	1,033	1	10,330	760	14.696
1 mmWS	0.0000981	0.0981	9.807	10,000	0.0000968	1	0.0736	0.001422
1 Torr 1 mmHg	0.001333	1.333	133.322	0.00136	0.001316	13.595	1	0.01934
1 psi 1 lb/sqi	0.06895	68.95	6,895	0.07031	0.06805	703.1	51.7	1

Calculating the Capability

c_g = gauge capabiliy
c_{gk} = critical gauge capabiliy
c_m = machine (test bench) capabiliy
c_{mk} = critical machine (test bench) capabiliy

σ = standard deviation of the test cycle
T = field of tolerance
$x_{\text{mean leak}}$ = arithmetic mean of the test cycle with test leak
$x_{\text{mean tight}}$ = arithmetic mean of the test cycle without test leak

For the capability of the test gauge (test unit or test circuit) is valid:

Test series with tight part and test leak

$$c_g = \frac{0{,}2*T}{6*\sigma} = \frac{0{,}2*(\left| x_{\text{mean leak}} - x_{\text{mean tight}} \right|)}{6*\sigma}$$

Test series with tight part, using the limits

$$c_g = \frac{0{,}2*T}{6*\sigma} = \frac{0{,}2*\left|\text{limit value} - 0\right|}{6*\sigma}$$

For critical gauge capability:

$$c_{gk} = \frac{0{,}1*(\left|\text{limit value} - 0\right| - \left| x_{\text{mean tight}} \right|)}{3*\sigma}$$

For the capability of the test bench (machine) is valid:

Test series with tight part and test leak

$$c_m = \frac{T}{6*\sigma} = \frac{\left| x_{\text{mean leak}} - x_{\text{mean tight}} \right|}{6*\sigma}$$

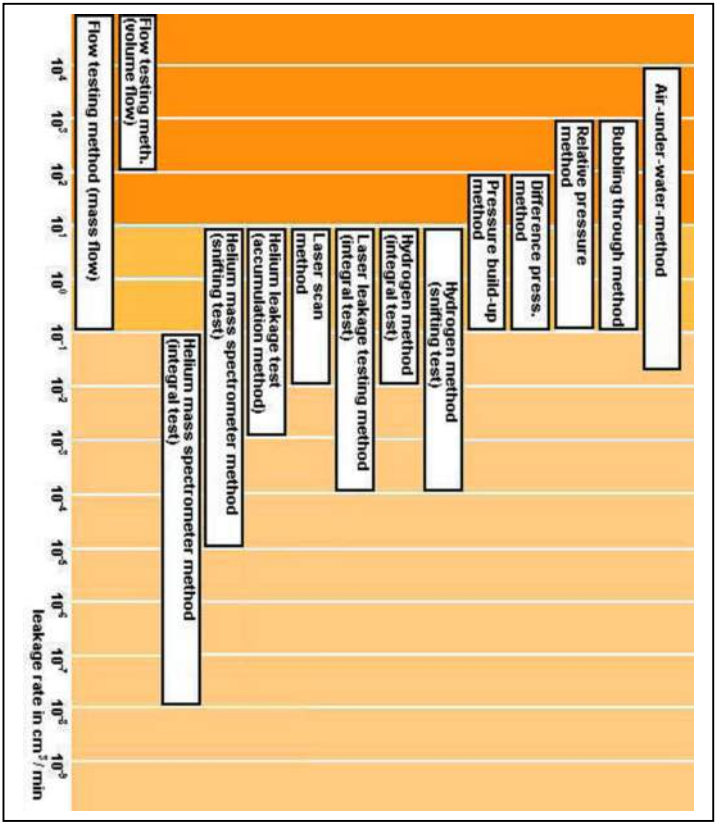
Test series with tight part, using the limits

$$c_m = \frac{T}{6*\sigma} = \frac{\left| \text{limit value} - 0 \right|}{6*\sigma}$$

For critical machine capability:

$$c_{mk} = \frac{0{,}5*(\left| \text{limit value} - 0 \right| - \left| x_{\text{mean tight}} \right|)}{3*\sigma}$$

Application area of the test methods



Overview Test Methods / Selection Criteria

	investment cost	operating costs	robustness	sensitivity	speed	localisation	depending of the operator	quantitative leakage rate detection	documentation of the measurement values	susceptibility against rough leak	susceptibility against temperature	suitable for elastic specimen	suitable for high test pressure
Air-under-water-method	low	middle	high	high	high	yes	yes	no	no	low	low	yes	yes
Bubbling through method	very low	low	high	middle	high	no	yes	no	no	low	middle	yes	no
Relative pressure method	low	low	high	middle	middle	no	no	yes	yes	low	high	no	yes
Difference pressure method	middle	low	middle	high	middle	no	no	yes	yes	low	high	no	no
Pressure build-up method	middle	low	middle	high	middle	no	no	yes	yes	low	high	no	yes
Hydrogen method (Sniffting test)	middle	high	middle	very high	low	yes	yes	no	no	middle	low	yes	yes
Hydrogen method (integral test)	high	high	middle	very high	middle	no	no	yes	yes	middle	low	yes	yes
Laser leakage testing method (integral test)	very high	high	low	very high	middle	no	no	yes	yes	high	low	yes	yes
Laser scan method	very high	high	low	very high	low	yes	no	yes	yes	middle	low	yes	yes
Helium leakage test (accumulation method)	high	high	middle	very high	middle	no	no	yes	yes	middle	low	yes	yes
Helium mass spectrometer method (sniffing test)	very high	high	low	very high	low	yes	yes	no	no	high	low	yes	yes
Helium mass spectrometer method (integral test)	very high	high	low	very high	middle	no	no	yes	yes	high	low	yes	yes
Flow testing method (volume flow)	low	low	high	low	middle	no	no	yes	yes	low	middle	middle	no
Flow testing method (mass flow)	middle	low	middle	high	middle	no	no	yes	yes	middle	middle	middle	no