17th IMEKO TC 10 and EUROLAB Virtual Conference
"Global Trends in Testing, Diagnostics & Inspection for 2030"
October 20-22, 2020.

Leak Test Of Encapsulated Systems With The Test Medium Compressed Air

Dr. Joachim Lapsien[1]

[1]*CETA Testsysteme GmbH, Hilden, Germany, joachim.lapsien@cetatest.com, +49(0)2103/2471-19*

***Abstract* – Encapsulated test parts, like micro-switches, clocks, relays, sensor systems, lamps, electronic control units are used in diverse industrial applications. Therefore these components have to fulfill a variety of requirements. This includes leak tightness against dirt and moisture (e.g. IP 67), as the penetration of liquids can cause serious malfunction. In the definition of the IP protection classes a description how to perform a suitable laboratory test is given. In the production line, this laboratory test cannot be transferred and used. Widespread is the use of the test medium compressed air for the 100 % in-line leak testing in industrial production lines. The test medium compressed air can be used down to an air leak rate of 10^{-3} mbar*l/s (depending on the test part). As waterproof usually an air leak rate of 10^{-2} mbar*l/s is assumed. By encapsulated test parts the inside of the test part cannot be filled with pressurized air. These test parts are tested in a hood, which is put under pressure. The pressure decay caused by a leakage into the internal volume of the test part is detected with high resolution. The concept of this test method and specific details to be considered are described.**

Keywords* – *leak test, leak tightness, IP protection classes, leak test, end-of-line test, encapsulated test parts, compressed air, differential pressure method.

I. TEST MEDIUM COMPRESSED AIR

The definition of the IP protection classes describes how a laboratory test has to be performed. But of course, such a test cannot be integrated as 100%-inline process in the production line. Based on the results of the laboratory experiments the requirements for a corresponding leak test in the production line have to be worked out. Ideally the test pressure and the permissible leak rate can be defined.

Depending on the leak rate a suitable test medium and test process have to be chosen to fulfill the technical requirement. Table 1 shows some of the most common used test media and their specific features. Widespread is the use of the test medium compressed air for the 100 % in-line leak testing in industrial production lines. The test medium compressed air can be used down to an air leak rate of 10^{-3} mbar*l/s (depending on the volume of the test part). If a sensor has to be waterproof, an air leak rate of 10^{-2} mbar*l/s (= 0.6 cm³/min) is commonly assumed. Typical examples of automotive sensors which are tested with compressed air are oil pressure sensors, ABS sensors, level sensors.

Table 1. Overview about industrial leak test methods (1 mbar*l/s = 60 cm³/min) [1]

Leak Rate / Test Medium	Methods / Remarks
> 10^{-2} mbar*l/s Water	<u>Detection of bubbles</u> Qualitative method Direct localisation of leaks
> 10^{-3} mbar*l/s Compressed air	<u>Pressure change</u> Quantitative method Easy to handle Depending on volume Temperature sensitivity Integral method Leak spray: Localisation of leaks
> 10^{-6} mbar*l/s Hydrogen (Forming Gas)	<u>Hydrogen concentration</u> Quantitative method No volume dependency No temperature sensitivity Sniffing: Localisation of leaks
> 10^{-9} mbar*l/s Helium	<u>Helium concentration</u> Quantitative method No volume dependency No temperature sensitivity Evacuation for small leak rates Sniffing: Localisation of leaks

II. LEAK TEST METHOD FOR DIRECT FILLABLE TEST PARTS

Test parts with small volumes, which can be filled directly, have often to be tested in a very short total test time by the use of compressed air.

The overall test consists of the consecutive phases: filling, stabilizing, testing and dumping. In the filling phase, the test part has to be filled to reach the test pressure. The stabilizing phase is necessary so that air disturbances (caused by the filling process and generated by the switching of the internal valves of the test device) can subside. In case of a positive gauge test pressure, the air is compressed adiabatically during the filling process, which heats up the air. So, the temperature of the compressed air has to adjust to the temperature of the test part. In the testing phase, the pressure decay is measured and compared with the permitted tolerances. The testing phase must be long enough to generate a significant measurement value. In the testing phase mostly a very sensitive differential pressure sensor is activated to measure the pressure decay with high resolution. A stable measurement phase is characterized by the criteria that the leakage-induced pressure decay is proportional to time. Finally, the dumping phase follows (see Fig. 1).

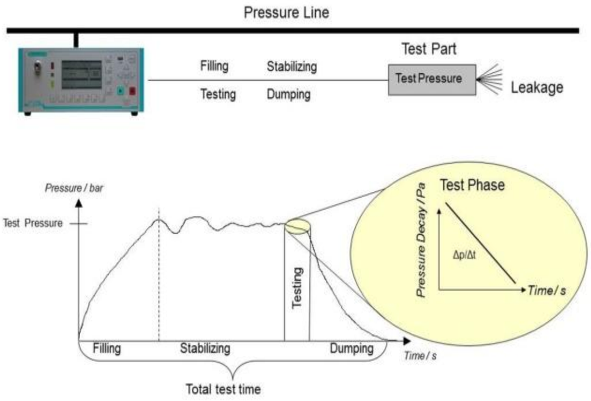

Fig. 1. Principle of the pressure decay test of direct fillable test parts [2].

The expected pressure decay in time in the testing phase can be calculated by the use of the so-called leak rate formula. This is a calculatory approximation for the leakage induced pressure decay in a stable test regime (eq. (1)):

$$\frac{\Delta p}{\Delta t}\left[\frac{Pa}{s}\right]=\frac{Q_L\,[cm^3/\min]}{V_{eff}\,[cm^3]}\bullet\frac{100.000\,Pa}{60\,s/\min} \qquad (1)$$

where

$\Delta p/\Delta t$ = Pressure decay in time

V_{eff} = Effective test volume
This is the sum of the volumes of the test part, the adaption, the measuring line and the measuring circuit inside the test device

Q_L = Leak rate (1 mbar*l/s = 60 cm³/min)
The air escapes into the ambient atmosphere with an atmospheric absolute pressure of approx. 100.000 Pa.

III. LEAK TEST METHOD FOR ENCAPSULATED TEST PARTS

Encapsulated test parts cannot be filled inside with pressurized air. A typical example to demonstrate this test method is an encapsulated photoelectric sensor (see Fig. 2). These types of test parts are placed in a hood which encloses the test part as closely as possible. The hood is pressurized. The temporal pressure decay caused by a leakage in the test part is measured. This type of test is called "closed component test" or "hood test".

Fig. 2. Photoelectric sensor as an example for a encapsulated test part [3].

Hereby, the following problem occurs: If the test part has a major leak (so-called gross leak), it is already filled with compressed air during the filling phase of the hood. In this case, only the tightness of the hood surrounding the test part would be measured. Therefore it has to be controlled in the first step that the test part has no gross leak (gross leak test). After this, the fine leak test is performed by means of a pressure decay measurement (see above).

The gross leak test is done in the following way (see Fig. 3): A reservoir volume, which is integrated in the test device, is filled to a pressure p_1 and separated from the pressure regulator. Then the check valve of the internal reservoir volume is opened and the air is flooded through the measuring line into the hood. Hereby, the pressure decreases to a lower pressure p_2. The ratio p_2/p_1 is a measure for the volume which is filled. The pressure values are mostly measured with a gauge pressure sensor.

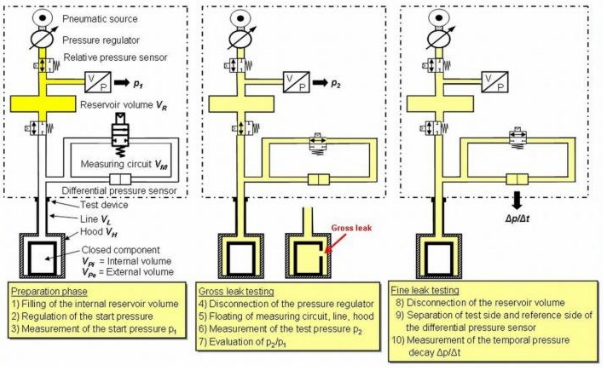

Fig. 3. Principle of the leak test of encapsulated test parts. The total test consists of two steps: After the gross leak test the fine leak test follows [4].

If the test part has no gross leak, eq. (2) applies:

$$\frac{p_2}{p_1} = \frac{V_R}{V_R + V_M + V_L + V_H - V_{Pe}} \qquad (2)$$

In case of a gross leak, the internal volume of the test part is filled additionally (eq. (3))

$$\frac{p_2}{p_1} = \frac{V_R}{V_R + V_M + V_L + V_H - V_{Pe} + V_{Pi}} \qquad (3)$$

where

V_R = Reservoir volume
V_M = Volume of the measuring circuit
V_L = Volume of the measuring line
V_H = Volume of the empty hood
V_{Pe} = External volume of the test part
V_{Pi} = Internal volume of the test part (filled in case of a gross leak)

These relationships are a result of the ideal gas equation, assuming constant temperature (isothermal change of state). In the initial state, the volumes are at atmospheric pressure level, so that in these formulas, the pressures are to be used as positive and negative gauge pressures.

IV. APPLICATION EXAMPLE

A sensor system should be waterproof (assumption: leak rate of 0.6 cm³/min) and is tested at a pressure of 100 mbar. The displacement volume (external test part volume) of the mounted sensor system (dimensions: 2 cm x 4 cm x 1.5 cm) is 12 cm³. The system is encapsulated. The test part must therefore be tested in a hood. The connector area is leak-tight and has not to be sealed in the hood. The inner volume of the test part that can be filled with air is 30 % of the displacement volume, corresponding to 3.6 cm³. This volume is filled in case of a gross leak. The mounting tolerance is specified with +/- 0.15 mm in x-, y-and z-direction.

This results in a displacement volume of 12.257 cm³ for a test part with maximum tolerance and a displacement volume of 11.747 cm³ for a test part with minimum tolerance. The "tolerance breathing" is 0.51 cm³ and is less than the inner volume of 3.6 cm³ filled in the case of a gross leak. Thus the metrological feasibility is given at least in principle.

The design of the test hood is carried out considering assembly tolerances and handling aspects. In this case, a circumferential gap of +0.5 mm between hood and nominally dimensioned test part is suitable. This results in an empty volume of the hood of 13.776 cm³.

An internal reservoir volume of 20 cm³ was installed in the test device.

The internal measuring circuit of the test device has a volume of 6 cm³. The measuring line (length: 1.0 m, internal diameter 4 mm) has a volume of 12.56 cm³.

The calculated values resulting from the test piece tolerances are shown in Table 2.

Table 2: Pressure conditions and pressure loss gradients for the various test piece tolerances [5]

	Test part tolerance		
	+/- 0 mm	+0.15 mm	-0.15 mm
Empty hood volume	13.776 cm³	13.776 cm³	13.776 cm³
Displacement volume	12.000 cm³	12.257 cm³	11.747 cm³
Residual hood volume	1.776 cm³	1.519 cm³	2.029 cm³
Internal reservoir volume	20 cm³	20 cm³	20 cm³
Measuring line volume	12.56 cm³	12.56 cm³	12.56 cm³
Measuring circuit volume	6 cm³	6 cm³	6 cm³
Reservoir fill pressure p_1	200 mbar	200 mbar	200 mbar
Hood pressure p_2 (non gross leak)	99.2 mbar	99.8 mbar	98.5 mbar
Ratio p_2/p_1 (non gross leak)	49.58 %	49.90 %	49.27 %
Hood pressure p_2 (gross leak)	91.0 mbar	91.6 mbar	90.5 mbar
Ratio p_2/p_1 (gross leak)	45.52 %	45.79 %	45.26 %
Leak rate	0.6 cm³/min	0.6 cm³/min	0.6 cm³/min
Test volume	20.336 cm³	20.079 cm³	20.589 cm³
Pressure decay gradient dp/dt	49.2 Pa/s	49.8 Pa/s	48.6 Pa/s

Since the exact tolerances of the serial parts are not known during the production process, it is necessary to determine a suitable test device setting for all permitted tolerances. The values listed in the table serve this purpose:

The minimum pressure ratio for non-gross leak parts is 49.27 % and the maximum pressure ratio for gross leak parts is 45.79 %,

If a pressure ratio of less than 45.79 % is registered for a test part, the test is aborted and the test part is evaluated as NOK. This test part has a gross leak.

All test parts that have a pressure ratio value greater than 49.27 % have no gross leak.

Therefore, the difference in pressure ratio between a gross leak part and a non-gross leak part is at least 3.48 % (= 49.27 % - 45.79 %). For test part tolerances within +/- 0.15 mm, a clear distinction between gross and non-gross leakage is thus possible.

If the test part has no gross leak the fine leak test follows. The pressure decay is measured and compared with the permitted tolerance limits.

Since the pressure in the hood depends on the tolerance of the test part, the pressure is refilled to the test pressure of 100 mbar in a refill phase before the fine leak test, so that the same conditions regarding the test pressure are always present in the fine leak test.

Table 2 shows that the pressure decay gradient depends on the residual hood volume, i.e. empty hood volume minus displacement volume of the test part. To be on the safe side, the smallest pressure gradient of 48.6 Pa/s is taken as a basis. For a process-safe signal (i.e. when a C_g-value > 1.33 is required), approx. 30 to 40 Pa are required in practice. Thus, a pure measuring time in the order of approx. 1 s can be assumed. In this example, the total test time for the hood test results from the sum of the phase times from reservoir filling (1 s), flooding (1.5 s), refilling to 100 mbar (1 s), stabilizing (1.5 s), measuring (1 s), venting (0.5 s). Thus the total testing time, consisting of gross leak detection and fine leak testing under consideration of process safety, amounts to approx. 7 s (including internal delay times of the testing device).

Due to the pressure decay gradient in the order of approx. 49 Pa/s and a difference of approx. 3.5 % between a gross leak part and a non-gross leak part, a leak tester with gauge pressure sensor can be used. Hereby the gauge pressure sensor is used for monitoring the test pressure and for the gross leak test as well as in high-resolution mode for pressure decay measurement.

However, if pressure gradients in the range of 1 to 30 Pa/s are to be measured, a leak tester with differential pressure sensor must be used.

V. PRACTICAL APPLICATIONS

A. Leak test of an encapsulated electronical display

For the leak test of an encapsulated display with integrated electronics (see Fig. 4), a specific hood (see Fig 5) is used. This hood encloses the outer contour of the display body with just 0.5 mm distance. In a manual workstation, a press is used to close the hood. The lower half of the hood is mounted on a drawer system. The display is inserted and the drawer is moved in the test position. Now, the upper half of the hood is closed by using a manual press. The measuring line of the leak test device is connected to the upper half of the hood. The leak test process is controlled by the leak test device.

Fig 4. Encapsulated display with integrated electronics [6].

Fig. 5. Fixture used for the leak test of an encapsulated display. The lower half of the hood is mounted on a drawer system. The upper half of the hood is mounted on a manual press [7].

B. Detection of assembly defects

With an optimized instrument like the leak tester type CETATEST 515 in the variant "closed components, high resolution" (see Fig. 6), the assembly of microparts can be tested, too. The volume which can be filled with air can be taken as a measure to detect assembly defects like a missing o-ring. In a test part which has a fillable volume of 10 cm^3 and which can be filled directly, a volume difference of only 0.03 cm^3 can be detected by using a gauge pressure of 900 mbar. This corresponds to the volume of an o-ring of 12 mm diameter and 1 mm cross section.

Fig. 6. Leak tester type CETATEST 515 for the leak test of encapsulated test parts with small volume [8].

The leak test of encapsulated small volume test parts (external volume approx. 0.5 cm^3) has been realized in the production line with a total test time in the range of 1 to 2 s. This can result in several million test cycles in one year in a production line working to full capacity. The internal components in the test device must be designed accordingly for a long service life.

VI. PRACTICAL TIPPS

Fundamental physical effects (adiabatic temperature effects, disturbances in the compressed air) can hardly be influenced, but the test device can be optimized regarding the components which have a sensitive influence upon the test process.

The distinction between a test part with gross leak and a test part without gross leak is more difficult if the fillable internal volume of the test part is quite small compared to the sum of the other volumes (see eq. (2) and (3)).

If the tolerance breathing is greater than the volume that can be filled internally in the case of gross leak, no suitable test instrument setting can be found with regard to the clear recognition of gross leak and non-gross leak test parts. This test is technically not feasible.

In such cases it must be checked whether the tolerances can be reduced and thus the tolerance breathing can be decreased.

The resolution and the cycle time when testing small volume test parts can be optimized by the following measures:

- Use of a measuring line with a small inner diameter, provided this does not hinder the filling process too much. For example, a measuring line with 3 mm inner diameter has only 56 % of the volume of a measuring line of the same length with 4 mm inner diameter.
- Use of special internal switching valves that have an extremely low switching kick. This reduces the time until these air disturbances subside, induced by the valve kick.
- Reduction of the internal test volumes (reservoir and measuring circuit volumes).
- Use of a hood that encloses the test part as closely as possible. Depending on the tolerances of the test piece, it is possible to use precision hoods that "fit" to the outer contour of the test part with an air gap of just 0.2 mm.
- If a gauge pressure sensor is used to assess the pressure conditions, in practice at least a separation of 0.02 (2 %) between gross and non-gross leakage is required. If instead of the gauge pressure sensor a differential pressure sensor is used to measure the pressure ratios p_2/p_1, combined with a valve circuit adapted to it, even lower pressure ratios in the range of 0.003 (0,3 %) can be detected process-safe (as it is possible with the differential pressure test device CETATEST 515, see Fig. 6)).

In order to simulate borderline test parts, calibrated test leaks are usually used. These have a defined flow rate at a certain pressure which corresponds to the permissible leak rate. The test leak is pneumatically connected in parallel to a specially prepared leak-tight part (master part) and serves to simulate a borderline test part. The test leak is also used to perform a measurement system analysis.

VII. CONCLUSIONS

A big variety of encapsulated test parts can be leak tested by using compressed air as test medium. As these parts have to be tested in a hood, which is pressurized, it is of high importance, to check the technical feasibility by taking the tolerances into account.

The hood test is an elegant method to test encapsulated test parts and is able to clearly distinguish between gross leak and non-gross leak parts. By the use of very sensitive sensors and sophisticated measurement value processing impressive resolution can be achieved.

For the sake of completeness, it should be noted that sensor systems that are internally potted cannot be tested for leaks using this test method.

REFERENCES

[1] Overview about industrial leak test methods Summary: CETA Testsysteme GmbH, Germany.
[2] Principle: Leak test of direct fillable test parts Diagram: CETA Testsysteme GmbH, Germany.

[3] Encapsulated photoelectric sensor
Photo: CETA Testsysteme GmbH, Germany

[4] Principle: Leak test of encapsulated test parts
Diagram: CETA Testsysteme GmbH, Germany

[5] Pressure ratios and pressure loss gradients for different tolerances of the test part
Calculations: CETA Test Systems, Germany

[6] Encapsulated display with integrated electronics
Photo: CETA Testsysteme GmbH, Germany.

[7] Fixture to test an encapsulated display
Photo: CETA Testsysteme GmbH, Germany.

[8] Leak tester CETATEST 515
Photo: CETA Testsysteme GmbH, Germany.