

Quality Assurance through Leak Testing of Telemetry Components during Production

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Abstract

Products used in telemetry applications (e.g. sensors, transmitters, receivers, power supply units) must function reliably under a wide range of conditions. If they are used outdoors or are exposed to liquids or moisture, there is a risk of malfunction due to the ingress of liquids. These products must be leak-tight.

During IP protection class testing, prototypes are tested in the laboratory. This is a type test.

To minimise risk a leak test is integrated into the production process as routine test – usually as an end-of-line test. Every part produced is tested. The test medium compressed air is widely used.

Operation and external influences lead to cyclic temperature-related pressure changes in the product. Mechanical stress on seals and seams can lead to leaks in encapsulated products.

In other products, pressure compensation elements (membranes) are used to reduce this mechanical stress. These membranes are watertight but permeable to air. During the leak test, the product must be filled via the membrane. Sometimes an opening is provided in the plug connector through which the product can then be filled directly.

Depending on the type of product (encapsulated, filling via a membrane, direct filling), there are specific aspects to be considered in the leak test.

Key words: IP protection class, type test, routine test, leak test

Telemetry – Applications and risks

The demand for telemetry solutions is continuously increasing. According to a market study by Verified Market Research (VMR), an annual growth rate of more than 8% is expected until 2030 [1].



Fig. 1. Security camera with with telemetry module [2]

Traditionally long used is telemetry in industry, aerospace and space industry, the motor sport

sector, transportation, logistics and remote imaging.

More and more branches profit from the advantages of telemetry solutions, like medical applications, internet of things, wearables, security, environmental protection, agriculture, animal tracking, oceanography, condition monitoring, regenerative energy sector, just to mention some branches (see Fig. 1 and 2).

In telemetry, numerous sensors are used to measure various parameters such as pressure, acceleration, temperature, angle, speed, rotational speed and displacements. And the use of remote image transmission is widespread.

Typical components of telemetry networks are the sensor systems with amplifier, the transmitting unit, the wireless connection, the receiving unit, supporting units for power supply and systems for data evaluation and storage.

The sensor systems, the transmitter and receiver units in particular are exposed to many

external influences, such as temperature, harsh environments and outdoor conditions.

If one of these components is not functioning properly due to a leak, this can lead to malfunctions in this telemetry channel, which can result in serious problems.



Fig. 2. Moisture sensor with telemetry module used in agriculture [3].

To reduce the risk of leaks and to ensure that only properly manufactured and leak-tight products are used, they are also tested for leaks during the production process in the integrated end-of-line leak test as part of quality control.

Type test and IP protection classes

In the definition of the IP protection classes the tightness resp. the impermeability against particles, contamination, liquid and moisture is described by the IP code (DIN EN 60529 / ISO 20653).

The IP code consists of two digits IP XY: The first digit X indicates the impermeability to particles, while the second digit Y indicates the water resistance.

Tab. 1 describes the IP protection classes for water tests and the corresponding test conditions.

Tab. 1: IP protection classes for water tests and test conditions [4], [5], [8]

IP code	Description	Test
IP X0	Not protected	None
IP X1	Water drips vertically	Vertical drips
IP X2	Water drips (inclination by 15°)	Enclosure is tilted at any angle up to 15° on either side of the vertical.
IP X3	Water spray	Water spray at an angle up to 60° on either side of the vertical
IP X4	Splash water	Water splashes against the enclosure from any direction

Tab. 1 – continued

IP code	Description	Test
IP X4K	Splash water with increased pressure	Water splashes against enclosure from any direction with Increased pressure
IP X5	High-velocity water	Water directed against the enclosure from any direction as a jet
IP X6	Strong high-velocity water	Water directed against the enclosure from any direction as a strong jet
IP X6K	Strong high-velocity water with increased pressure	Water directed against the enclosure from any direction as a strong jet with increased pressure
IP X7	Temporary immersion in water	Enclosure is immersed in water temporarily (1 m depth for 30 min)
IP X8	Continuous immersion in water	Enclosure continuously immersed in water Conditions agreed between supplier and manufacturer Tests are more severe than IP X7.
IP X9	High-pressure steam-jet cleaning	Water directed against the enclosure from any direction Control panels or electrical equipment
IP X9K	High-pressure steam-jet cleaning	Water directed against the enclosure from any direction Equipment installed in road vehicles

The prerequisite for compliance with the corresponding IP protection class is that no harmful or performance-impairing influences occur.

The IP protection class tests are type tests. Prototypes and samples are tested in the laboratory for tightness against the ingress of moisture strictly in accordance with the specifications of the desired IP protection class. The test result is summarised in a certificate. This certificate is only valid for the tested product.

Leak test as routine test during production

Carrying out a type test involves a great deal of experimental work. These tests are carried out by specially equipped laboratories and institutes. Special test equipment is used, and the test part is exposed to moisture or liquid with varying intensity and exposure time, depending on the IP protection class.

It is obvious that such tests cannot be integrated in the manufacturing process. It is not possible to work with moisture or liquids.

And the test duration (exposure time to moisture or liquid) does not correspond in any way to the production cycle times commonly used in industry.

The IP protection class test does not provide any direct parameters for the specification of the leak test during production.

A parameter regime for the leak test must be found here, considering the test conditions of the IP protection class test and the loads that occur on the product during operation. For this purpose, the test pressure and the leak rate must be defined.

Information on the test pressure and leak rate can be derived indirectly from some definitions of the IP protection classes. For example, the conditions of the diving test provide an indication of the test pressure. As a rule, the test pressure and the direction of pressurisation (i.e. test with positive or negative gauge pressure) are determined by the manufacturer, taking into account the product properties and the loads during operation.

The following information on tightness and leak rate as a function of hole size can often be found in the literature (see Tab. 2):

Tab. 2: Overview about tightness, leak rate and hole size [6], [7], [8].

Tightness	Leak rate less	⊙ Hole
Water tight	10^{-2} mbar*l/s	10 μ m
Vapor tight	10^{-3} mbar*l/s	3 μ m
Bacteria tight	10^{-4} mbar*l/s	1 μ m
Oil tight	10^{-5} mbar*l/s	300 nm
Virus tight	10^{-6} mbar*l/s	100 nm
Gas tight	10^{-7} mbar*l/s	30 nm
Virus tight (assured)	10^{-8} mbar*l/s	10 nm
"Absolute tight"	10^{-10} mbar*l/s	1 nm

Leak rate 1 mbar*l/s = 60 cm³/min

This information is based on a simplified model: there is an ideal hole in a housing that has been evacuated to a negative gauge pressure of -1 bar (relative). If this is suddenly opened, the column of air above the cross-section of the opening streams into the housing at the speed of sound. This results in a relationship between the hole size and the volume flow, the so-called leak rate.

In reality, however, the leakage results from a large number of micro-leaks (e.g. in glued or welded seams). The leak rates listed in table 2 therefore serve as orientation values. In practice and depending on the product, other

leak rates may prove to be more suitable. If orientation values are used as a basis, there is a risk that the test may be too stringent with an excessively high reject rate. To be on the safe side, the determination of the leakage rate should be verified by laboratory tests. Here, test parts with different production qualities are tested for leaks using compressed air. A laboratory test is then carried out under the conditions of the desired IP protection class. A correlation can then be used to decide which leak rate is still tolerable.

Leak test using compressed air

The use of compressed air as a test medium is widespread in industrial leak testing. Compressed air is available in all production facilities. Measuring the pressure change due to leaks is an objective and quantitative measurement method that can be easily integrated into automated production lines. In contrast to testing in a water bath, the product is not wetted during the test and can be further processed immediately after the test (e.g. packaging and delivery).

Compressed air can be used for leak rates down to 10^{-3} mbar*l/s, corresponding to 0.06 cm³/min. A leak rate of 0.6 cm³/min is often used for industrial leak testing of products that are to be tested for watertightness.

The differential pressure method is often used to detect small leak rates with compressed air.

Here, the leakage-related pressure change in a pressurised or evacuated product is measured against a sealed reference volume (usually an encapsulated volume inside the test device) that is at the same pressure level. A sensitive differential pressure sensor with an internal resolution of 0.01 Pa is used for this purpose.

Such small pressure changes occur due to thermal noise, micro-vibrations and minimal movements in the test part, in the adaptation and in the pneumatic lines.

For this reason, the measured values are averaged, and the displayed value is usually rounded to 0.1 Pa or 1 Pa (= 1/100,000th of the atmospheric pressure).

Pressure gradients from approx. 1 Pa/s can be detected with leak test methods using compressed air. Test devices from the CETATEST 825 leak tester series (manufacturer: CETA Testsysteme GmbH, Hilden), for example, are suitable for leak tests using the differential pressure method.

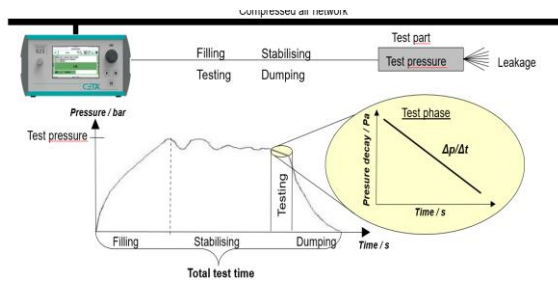


Fig 3: Principle of the pressure decay test [8]

A complete test process (see Fig. 3) for a directly fillable test part consists of successive phases: Filling, stabilising, measuring and dumping. Ideally, the filling and stabilisation times should be selected so that a stable state is achieved in the measuring phase. This is characterised by the fact that the pressure decay changes proportionally to the time. If the measured pressure decay value is within the permitted limit values, it is a good part. A sufficiently large spread of the measured value distribution between good and bad parts is necessary for a reliable testing process.

The leakage-related pressure gradient can be calculated using the so-called leak rate formula (1):

$$\frac{\Delta p [\text{Pa}]}{\Delta t [\text{s}]} = \frac{Q_L [\text{cm}^3/\text{min}]}{V_{\text{eff}} [\text{cm}^3]} \cdot \frac{100.000 \text{ Pa}}{60 \text{ s/min}} \quad (1)$$

Q_L Leak rate

V_{eff} Effective test volume
(test part, measuring line, adaptation,
test device measurement circuit)

$\Delta p/\Delta t$ Pressure gradient

The commonly used units for leak rates are "mbar*l/s" or "cm³/min", whereas (1 mbar*l/s = 60 cm³/min).

The leak rate formula can be used to estimate whether the compressed air test medium and the pressure decay method can be used.

Many industrial leak testing applications have pressure gradients of 10 to 50 Pa/s.

It should also be noted that the leak rate formula is based on ideal conditions, which rarely exist in the real production line.

So-called test leaks are used to simulate the allowable leak rate. These have a defined flow rate at a certain pressure. If they are connected in parallel to a master tight part, they can be used to simulate borderline test parts.

Application of the leak rate formula

A telemetry component is to be tested for leaks. The plug connector has an opening through which the product can be filled directly. The adaptation is carried out on the burr-free edge

of the connector housing. The fillable volume of the control unit is 80 cm³ including the plug connector area. The measuring line and the internal measuring circuit volume of the leak tester have a total volume of 14 cm³. This results in an effective test volume of 94 cm³. If a leak rate of 0.6 cm³/min is to be detected at a test pressure of 500 mbar (positive gauge pressure in relation to atmospheric pressure), this results in a calculated pressure gradient of 10.6 Pa/s in a stable regime. If the measuring time is 4 s, this corresponds to a leakage-related pressure decay of approx. 43 Pa as the rejection limit.

Types of products and their leak test

Directly fillable products

Some products have a plug connector that is not leak-tight. In the plugged-in unit consisting of plug and mating connector, the system is sealed to the outside.

In this case the plug connector can be used to fill the product directly.

Sometimes the plug connector is provided with a filling opening (see Fig. 4). A hole with a diameter of 1 mm to 2 mm is sufficient. The product can then be filled very reliably via this opening. For the sake of completeness, it should be noted that the "hole in the plug connector" feature is not accepted by all end customers.



Fig. 4: Example of a product with a hole in the connector area [8]

Sometimes a filling opening is only provided for the purpose of the leak test, which is then closed in a controlled manner after the successful leak test.

When adapting in the connector area or at an opening, it must be ensured that the test adapter does not move during the leak test.

This can be achieved with an end position lock of the test adapter or with a rigid stop. A "floating" adaptation should be avoided. Micro-movements can lead to movement-induced pressure fluctuations, which can have a disadvantageous effect on the test process (especially during the measurement phase).

Encapsulated products

Encapsulated products cannot be filled directly with compressed air. These are placed under a test hood that surrounds the outer contour as closely as possible and is pressurised. The

leakage-induced pressure decay into the product is measured. This type of test is known as a "closed component " or "hood test".

The following problem arises here: If the test part has a gross leak, it is filled directly with compressed air during the filling phase of the hood. In this case, only the tightness of the hood would be tested. Therefore, the first step is to check that the test part does not have a gross leak. This is followed by the fine leak test using the pressure decay measurement.

During the gross leak test, a reservoir volume integrated in the test device is filled to a starting pressure p_1 and disconnected from the pressure regulator. The shut-off valve of the internal reservoir volume is then opened, and the air streams into the hood connected to the test device. As the air from the reservoir volume is distributed over a larger volume, a lower pressure p_2 is created. The ratio p_2/p_1 can be used to pneumatically determine which volume is being filled and in this way is possible to detect of gross leaks.

If the test part does not have a gross leak, the fine leak test follows. The pressure decay from the pressurised hood into the interior of the test part is measured. The residual hood volume (i.e. the empty hood volume minus the displacement volume) represents the actual test volume. Taking into account the measuring line and the internal measuring circuit volume of the test device, the effective test volume is obtained.

The test hood is designed to be product specific. The test part tolerances and handling aspects must be taken into account when designing the hoods. Typical hoods have a gap distance between the maximum tolerated product and the hood of approx. 0.5 mm to 2 mm. The smaller the residual volume of the hood, the better the resolution for detecting gross leaks and the more sensitive the measurement of pressure losses.

A feasibility criterion is that the tolerance-related volume variation of the displacement volume is less than the internal volume of the product that is filled in the case of gross leakage.

It should also be noted that fully potted products cannot be tested for leaks using this method.

Products with pressure compensation element

Products in outdoor areas are exposed to a variety of environmental influences. Temperature-related pressure fluctuations can lead to overpressure or underpressure inside the system. As a result, the seals, welded and bonded seams are subjected to high stress and can become leaky. If there is then negative gauge pressure in the

product, there is a risk of moisture and liquid being drawn into the interior of the system. This can lead to serious faults in electronic components and severely impair their function.

For this reason, pressure compensation elements (membranes) are often used for ventilation. These enable pressure compensation while at the same time protecting against oil, water and particles. The pressure compensation element is often mounted behind a cross or perforated grid to protect it from dirt and mechanical damage.

Membranes made of expanded polytetrafluoroethylene (ePTFE) are widely used. The hydrophobic and oleophobic material is produced in thin layers and the flow is adjusted by stretching. These membranes are available in weldable and adhesive versions. A fundamental problem with this type is that often only the minimum flow rate is specified in the data sheet. The typical flow rate can be up to 2 to 3 times greater than the minimum flow rate.

In addition to this very common type of membrane, there are also membranes that are perforated by exposure to ion beams. This is followed by a chemical etching process. In this way, the pore density and pore size can be "adjusted" in a defined manner. These track-etched membranes are characterised by the fact that the average flow rate including the flow spread width can be specified and is indicated in the data sheet. This is very helpful for the planning of projects.

There are also membranes in which a granulate of porous PTFE is pressed under isostatic pressure and then sintered. This processed material is peeled to produce sintered membranes. These also have a relatively defined flow range.

Due to the handling of the pressure compensation element and its assembly, it must be checked whether it is undamaged and has been assembled correctly. During the membrane test, a reservoir volume inside the test device is brought to a defined pressure. When the air flows from this reservoir volume through the membrane into the test part, the pressure decrease is delayed due to the limited flow through the membrane. The change in pressure over time depends on the condition of the membrane (not fully welded or bonded, damaged, missing membrane). If the pressure is measured shortly after the start of the flooding process, the state of the membrane can be qualified in this way (see Fig. 5). The batch-dependent variation of the membrane flow rate must be considered critically here. This must be considered when planning the test process.

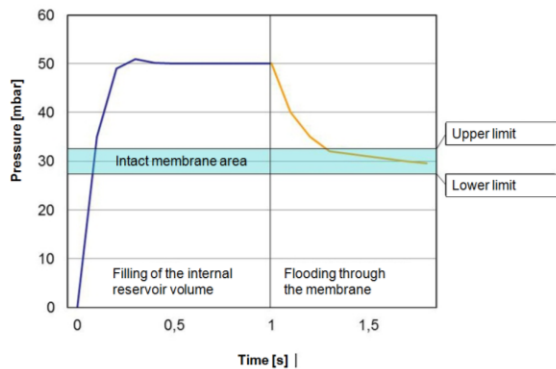


Fig. 5: Pressure-time diagram for the membrane test [8]

Once the membrane has been checked for correct installation, the leak test follows. The product must be filled via the pressure compensation element, which is installed on top of the ventilation opening. The required filling time depends on the permeability of the membrane, the flow-active area of the membrane, the applied pressure, and the volume to be filled. This time is significantly longer than for a test part with the same volume that can be filled directly.

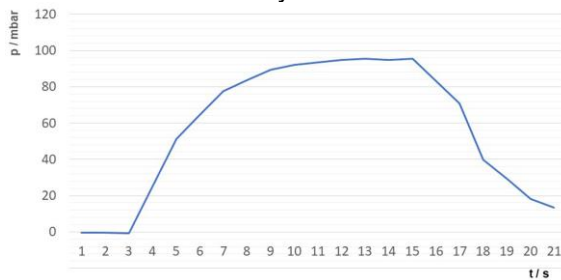


Fig. 6: Pressure-time diagram inside a test part when filled with a constant pressure of 90 mbar through the membrane (prepared test part with the possibility of measuring the pressure inside the part) [8].

Hereby only the pressure in front of the membrane can be measured. Preliminary tests must be carried out to ensure that the test pressure inside is actually reached (see Fig. 6). The filling process and therefore the overall test time can be shortened in some circumstances by pre-filling with a slightly higher pressure before the actual filling phase. The specifications regarding the sudden pressure load on the membrane must be considered. Overfilling must be avoided. Batch scattering must also be taken into account when planning the process.

If the product also has plug connectors that only need to be tight when plugged in, it is recommended that these are also pressurised with the test pressure during the leak test. This prevents the pressure in the test part from

gradually decreasing via the plug connector and pseudo leaks from being measured.

Additional comments

The leak test in the production line usually takes place at ambient temperature. The pressure loads on the product due to hydrostatic pressure and thermally induced pressure changes during operation can be simulated during the leak test by selecting the appropriate test pressures.

Micro-gaps that form under thermal stress due to the different material expansion coefficients (metal, plastic) cannot be simulated by different test pressures. Other test methods, tests or appropriate material selection must be used to ensure that this does not pose a problem during operation of the product.

The mating connector used for the electrical test can also be used as a leak test adapter with modifications. As the electrical test is associated with temperature input, it should not be carried out at the same time as the leak test. If consideration is given to carrying out the two tests in parallel and in one clamping, the heating phase must be completed before the measuring phase of the leak test begins. Then the test would always take place in the same thermal state. The feasibility should be verified by preliminary tests.

References

- [1] Verified Market Research (VMR) Global Telemetry Market Size and Forecast Report ID: 38312 | Published: Jan 2024 www.verifiedmarketresearch.com/product/telemetry-market/
- [2] © jakit17 - stock.adobe.com
- [3] © Sittichok - stock.adobe.com
- [4] Overview IP protection classes ITS GmbH Innovative Mess- und Testsysteme GmbH
- [5] Overview IP protection classes Asskühl GmbH & Co. KG
- [6] Leybold GmbH, Köln https://www.leyboldproducts.de/media/pdf/10/0f/8b/FVT_Grundlagen_der_Vakuumtechnik_DE591eea2256c34.pdf
- [7] Deutsche Gesellschaft für Zerstörungsfreie Prüfung e.V., Berlin | FAQ, V9 <https://www.dgzfp.de/foerdern-ernetzen/fachausschuesse/fa-dp/>
- [8] Measurements, photos, graphics, tables CETA Testsysteme GmbH, Hilden