A DRY AIR LEAK TEST PRIMER

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REVIEW OF COMPRESSIBLE FLUID DYNAMICS

What causes a leak?

When the homogeneity of materials used in the construction of a product is under question, the need for determining the degree of this homogeneity is the purpose for leak testing. In a sense, everything leaks. One of the problems encountered by an engineer faced with this situation is to determine the exact level of permissible leakage for any given product. He must take into account all of the factors relating to the product including the costs of the process involved in testing for this “acceptable leak rate.”

As an example, a container to store a nuclear weapon might require a leak rate not to exceed 10^{-9} cubic centimeters per second of helium (1 ounce in 20,000 years) where as an automotive transmission assembly would typically be tested for leaks not to exceed 10 cubic centimeters per minute of dry air. It is obvious that it would be ridiculous to test the automotive automatic transmission to the leak rate standard of the nuclear weapon storage container, and just as ridiculous to test the nuclear weapon storage container to the specifications of the automotive automatic transmission. This is an extreme example, but it can be seen that it is important to determine the maximum allowable leak rate for a particular application.

A leak is caused by a difference in pressure that creates a flow of fluid. In the case of a liquid, this may be merely the head of the liquid exerted against its container. If the container has defects causing a path to be formed by which the fluid under greater pressure can escape, the laws of fluid dynamics concerning equalization of pressure become apparent. Several factors influence this phenomenon. In the case of liquids, it is primarily temperature that directly affects viscosity. In the case of gases, it is temperature, pressure and the gas constant for that particular gas. This also affects the ability to detect leaks using air as the medium.

Many factors affect the integrity of parts to be leak tested including porosity caused by casting techniques, welding or manufacturing processes; cuts in sealing materials; cracks due to various causes; and the fitting of several parts in an assembly.

RELATED PROCESSES

There are several related aspects of leak testing that will be defined before going onto leak testing itself. Some processes used to determine acceptability of parts in assemblies use air as the test medium as opposed to fluids. These include through-hole detection, part present and part-in-place detection.

Through-Hole Detection

There are two reasons for testing by the through-hole detection method. One is obviously to see if a hole has been produced in a part where desired. The other is to determine if there are any undesirable restrictions in this hole due to manufacturing processes such as casting flash, etc.

The same types of sealing and fixturing techniques that are generally used for through-hole detection are also used in leak testing. A standard leak test system could also be used for through-hole detection except that a system of this complexity and cost is not usually needed for this application. There are two basic methods utilized for through-hole detection: the pressure increase method (back pressure) and the flow method.

The **pressure increase method** uses a restricted air flow through either a fixed or adjustable orifice injected into a hole under test. If, in a given period of time, a pressure switch used to sense back pressure is not actuated, then the hole exists and an accept condition is displayed. Conversely, if the pressure switch does actuate, an excessive pressure increase is indicated due to blockage and a reject condition is displayed. The sensitivity of this system is limited by the quality of the pressure switch used. It can also be adjusted for accuracy by manipulating the test pressure in conjunction with the flow limiting orifice to determine the best set of conditions for any particular application. When a relatively large hole is to be detected for presence only, it will be found that a large orifice with a fairly inexpensive pressure switch used at pressures in the 5 - 10 PSI range will be adequate. When the detection of a small opening is attempted by this process, the selection of the appropriate flow limiting orifice and pressure switch at a pressure usually not exceeding 20 PSI is important. When utilized correctly, this system can be very effective.

The **flow method** uses some means of detecting differential pressure across an orifice. This differential pressure is classified directly with accept and reject results and displayed accordingly. Sometimes other methods of flow detection are used, i.e., variable area meters (rotameters), laminar flow elements, and thermal mass flow meters. The flow system may be used to detect very small holes or even to classify conditions existing within the hole. It is basically the system that has been used for many years in air gauging.

Part Present and Part-in-Place Detection

Part present detection and part-in-place detection usually use the pressure increase method as described above. The method of fixturing for part present detection is extremely critical. In many cases, this method is combined with detecting whether or not a component is in a proper relative position in an assembly.

TYPES OF LEAK TESTERS

The wide range of acceptable leak rates and specified test pressures make the need for various leak testing methods apparent. Each method is capable of handling a different - but limited - range of applications. Production leak test equipment varies in sophistication from water tank dunking units which allow visual inspection of gross leaks to mass spectrometer detection which can routinely determine leaks as small as 10^{-7}. A basic understanding of each method is necessary since there is considerable variation in the speed, accuracy, repeatability, cost and detection range of these test methods.

Water Immersion Method

One of the oldest ways known to find leaks is by the water immersion method, sometimes called dunk testing. Every tire repair shop has its dunk tank for finding small leaks in tires. The tire is simply inflated with air and held under water while the repairman observes from where the bubbles come. This same method may be applied to almost any part and has one important advantage: it obviously indicates where the leak is. There are, however, several disadvantages. These include the following:

1. Only roughly indicates the magnitude of the leak.
2. Requires operator observation of the leak and therefore, is difficult to automate.
3. Presents housekeeping problems because of the water involved.
4. Causes corrosion problems on ferrous metal parts.

Quite often, this method is used as a backup for a dry air leak test operation to locate leaks in rejected parts. This back up operation has several advantages which include location of the leak for possible correction, only exposing those parts already indicated as rejects to corrosion, and only having an operator observe parts which are already shown to have leaks.

Another problem associated with water immersion leak testing is that of contamination of the water. This usually occurs because of dirt, oil, etc. on the parts being tested. These systems are sometimes supplied with a circulating water filtration system in an attempt to keep the water as clean as possible so that leaks may be more easily observed.

Seals used in the water immersion method are the same type as those used in dry leak test methods. Quite often, manually actuated sealing techniques are utilized. One other minor advantage of the water immersion test method is that the operator can discriminate between leaks in the part and leaks from faulty seals. Sometimes this is a dangerous practice as part leaks may occur at sealed surfaces and can thereby mislead the operator.

Pressure Decay Testers

The so-called pressure decay method of leak testing might better be called the pressure change method. The pressure change method may operate in any area of the pressure domain from below sub-atmospheric (so called vacuum) to a high enough level to be dangerous. Always remember that air is a compressible -- the larger the volume, the lower the pressure required to be dangerous.

Early systems (and some still in use today) use a simple pressure gauge observed by an operator.

Moore Products Detector

The first automatic pressure decay leak testers were built with pneumatic differential pressure sensing components and electro-mechanical timers. The originator of these units was Moore Products Company of Spring House, Pennsylvania. The first units were produced in the early 1940's. Moore Products manufactured many of their own pneumatic components, and still do today.

This system is based on a differential pressure system that uses a reference chamber which is brought to the same pressure as the test part, isolated and allowed to decay. This was the first dry air leak test system to offer objective testing with settable accept and reject limits.

Variations of this system were offered by other manufacturers through the 1950's and 1960's. Basically, most of these successive systems utilized the original Moore Products type concept, with minor refinements. There were no major improvements in testing speed or repeatability due to the pneumatic differential type pressure sensor used.

Electronic Memory Leak Tester

Several brands of leak testers use an electronic memory to eliminate the need for a reference chamber. These leak testers automatically perform the following operations:

1. Brings the part to the test pressure.
2. Allows a programmed time for the air pressure to stabilize.
3. Electronically memorizes the initial test pressure.
4. Measures the pressure change (leakage) and compares the pressure change to programmed accept/reject leakage limits.
5. Provides accept or reject output and indication.

Another feature offered is the adiabatic compensation network. When the part is pressurized, there is adiabatic heating of the air caused by compression of the air into the test part. With this air being heated to temperatures above the test part temperature, there is an apparent pressure loss. The apparent pressure loss as the air cools when heat is conducted to the part during pressure change causes a false leak indication.

The compensation network feature utilizes an electronic network to offset the adiabatic heating effect. This allows stabilization time to be reduced.

Other Pressure Decay Testers

Other units use micro-processors to test parts to multiple limits and also to use one leak tester for several different parts, each with different limits.

Some units also offer a flow readout in engineering units per unit time by using a micro-computer to perform the equation dp/dt for a given volume. All pressure decay leak testers are volume sensitive, i.e., the internal volume of a part to be tested must be known in order to calculate the actual leak rate. Additionally, the volume must not change significantly from part to part.

Flow Type Leak Testers

There are several variations of flow type leak testers. One is the differential pressure system where the differential pressure across a pressure drop element is proportional to the leakage from the part. With pressure differential systems, there are laminar or turbulent flow elements, each having a specific advantage. These are as follows:

1. Variable area flowmeters where a tapered glass tube measures the flow rate by the height of a floating element in the tapered tube.
2. Laminar flow elements which produce a differential pressure linear with flow rate using a labyrinth to give a high L/D ratio thereby reducing the Reynolds number.
3. Thermal mass flowmeters electrically measure the air flow by measuring heat loss by heating (thermal) elements.
4. Bubble jars where the air flow is measured by flowing air bubbles from a tube immersed in water in a sealed glass jar.

In all types of these flowmeters, there is some pressure loss occurring across the measuring element. Some of them require extended time to allow the stable measurement to be made.

Basically, the part to be tested is subjected to the test pressure and then maintained at that pressure while the flowmeter measures the flow into or out of the part to maintain that pressure. A “fast fill” circuit is sometimes used to bypass the flowmeter upon initial pressurization for large volume parts. An “overfill” system that pressurizes the part to slightly more than the test pressure and then quickly bleeds off to the test pressure can act the same as the “adiabatic compensation circuit” of a pressure decay tester.

Flow testers are not subject to internal volume changes when determining leaks as they measure flow directly in engineering units per unit time. Therefore, it is simpler to set them up for multiple limits than pressure decay testers.

Both the pressure decay and the thermal mass flowmeter flow units can comfortable detect leak rates as low as 0.5 SCCM at pressures as high as 500 PSIG.

Mass Spectrometer Method

The mass spectrometer method of leak detection offers the most sensitive form of leak detection. Leaks as low as 10^{-7} can be routinely detected on a production basis. With this system, the test part is sealed and the air is evacuated to a predetermined vacuum level. The test volume is then saturated with helium. Any helium leaking out of the test part will then be quantified by the mass spectrometer and indicated as a leak or a specified amount.

AIR VS. LIQUID LEAK TESTING

The reason for testing many automotive components is to make sure they do not leak a specific liquid when in use. So, why not test them using that specific liquid as the test media? What are the relative merits and disadvantages of using air or liquid for the leak testing media?

Air is a compressible media with a relatively low viscosity compared to common liquids. This means that air travels through a leak path approximately 200 times faster than liquids. Air has essentially no surface tension. This allows it to escape much more easily than liquid through a small hole.

It is very important, however, to remember that air can go through holes that do not leak liquid. This is one reason for requiring a specified maximum allowable **air** leakage rate.

The primary advantage of using air as a test fluid is speed in leak testing.

THE "SHALL NOT LEAK" SPECIFICATION

An engineer writing a specification for a new part or assembly that states "shall not leak" is not doing his job very well. Shall not leak what? And at what pressure?

Everything leaks. It is only relative to the situation. Every individual component will have some amount of leakage. Designating "zero" or "no" leakage of a certain liquid helps to establish a leak rate specification. However, since most components are tested with air to prevent this liquid leakage, "no leak" of air or other gas cannot be specified.

Maximum allowable leak rates are typically specified as so many cc/minute of air or other gas at a specified test pressure. The first leak test parameter that must be decided when looking for a production leak test system is what leak rate is acceptable for the part or assembly to be tested. Establishing this leak rate not only simplifies the leak equipment for a particular application, but has important economic implications as well.

If the leak rate specification is needlessly stringent, manufacturing costs may rise out of line. If the leak rate specification is not made stringent enough, the performance and reliability of the product may be unacceptable causing excessive warranty costs, unhappy customers, and in some cases perhaps even hazardous situations.

The appropriate maximum allowable leak rate for a product can be determined in several ways. If the product has been manufactured for sometime, it may be sufficient to take production samples and have them leak tested in a laboratory. Inexpensive and easy to operate equipment is available that will enable a determination of the proper test pressure and acceptable leak rate to be established for a given product.

To establish leak rate specifications for a product, two general rules may be applied. These are:

1. At a pressure of 20 PSIG, a maximum allowable leak rate of 12 SCCM of air will usually mean a part will not leak SAE 30 weight oil.

2. At a pressure of 20 PSIG, a maximum allowable pneumatic leak rate of 5 SCCM of air will usually mean a part will not leak water.

These general rules are based upon experience and reflect viscosity differences between air, oil and water. Many other factors have an effect on the relationship between pneumatic leak testing and the desired results. Among these are the following:

1. Surface tension of the liquids which tends to prevent water and oil escapement through holes of a size which would leak air.
2. The labyrinth effect which also tends to leak air when no liquids can penetrate.
3. Corrosion which tends to stop leakage, especially from ferrous metal parts.

When conditions of extreme parameters are involved, extensive pre-testing of prototypes may be required to establish an appropriate leak test specification.

Another point to remember is that test pressures as near as possible to ambient will be easier to work with even though a test pressure with a greater difference from ambient will result in a higher air flow rate through any defect. The loss of sensitivity of the pneumatic dry air leak test system at lower test pressures is greatly outweighed by the additional sealing and safety problems encountered using higher test pressures.

The information in Table 1 (attached) shows a wide range of minimum acceptable leak rates and test pressures specified for various parts. Obviously, no single piece of test equipment could test all these parts. Consequently, a number of leak test methods, as described above, have been developed. Each method is capable of handling a specific range of applications.

ECONOMICS OF LEAK TESTING

Several aspects of the economics involved in leak testing will be discussed here. The first is the necessity for 100% inspection. In some cases, the need for 100% inspection is obvious. For example, a medical component which must be leak free must be 100% checked with as much effort as is humanly possible in order to eliminate defective parts. Also, wherever the safety aspect is encountered such as in automotive brake components, it is obvious that a 100% leak test inspection is required with the equipment designed to be as fail-safe as possible.

However, in other cases, the need for 100% inspection may not be as obvious. Small sub-components of assemblies may not be 100% leak tested because of their non-critical nature and also because of reasoning which indicates that any leakage will be detected during a final test. This final test may be primarily a functional test utilizing expensive and complicated test apparatus. In this case, it must be considered that any leak failures during final test are wasting the resources of this equipment. In-process testing, a relatively inexpensive form of leak testing, may have prevented these non-functioning parts from ever reaching the final test stage. The cost of the salvage or non-salvage of a defective assembly which ultimately reaches final test should be weighed in proportion to the cost of in-process test equipment.

The cost of warranty repairs, if applicable, must also be considered when evaluating 100% leak testing. Perhaps the most difficult aspect to assess economically is that of customer satisfaction. A common saying throughout the leak test industry is that “all leak test instrumentation sold to the automotive industry should have their meters calibrated in drops on the garage floor.”

The second aspect of the economics of leak testing is the determination of a realistic allowable leak rate. In many cases, the selection of the test parameters for leak testing a part or assembly will have a higher economic impact than the decision of whether to leak test on a 100% basis. The design of the leak test system should fit the application and, with good manufacturing practices, a minimum amount of parts or assemblies will be rejected by the leak test equipment.

Always remember that no test operation builds or designs quality into a product. These operations only determine if the quality is there in the first place. Ideally, no test operation should ever find a defective part. This, however, does not diminish the importance of testing. The best equipment for the application should always be purchased. This equipment, in turn, should always be properly maintained so as to insure consistent accuracy and repeatability.

LEAK TEST EQUATIONS

The most common gas used for leak testing is air. For all practical purposes, air reacts as a perfect gas. This means that in the general gas law, PV=MRT, R=1. Therefore, the combination of relationships expressed by Boyle and Charles reduce to:

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$$

which means that air reacts directly with its absolute pressure and inversely to its absolute temperature. If we assume that a system to be leak tested is isothermal (temperature of gas held constant) the test cavity can be equated to atmospheric conditions and the formula rewritten to:

$$P_{test} = \frac{P_{atm} V_{atm}}{V_{test}}$$

Now, since the loss in test pressure

$$\Delta P = P_{test} - P_{1test}$$

we can substitute as follows:

$$\Delta P = \frac{P_{atm} V_{atm}}{V_{test}} - \frac{P_{1atm} V_{1atm}}{V_{1test}}$$

and simplifying

$$\Delta P = \frac{P_{atm}}{V_{test}} \times (V_{atm} - V_{1atm}) \quad \text{then} \quad \Delta P = \frac{P_{atm}}{V_{test}} \times V_{(loss)}$$

Standard pressure being 14.7 PSIA and the conversion being 27.7 inches of water per PSI, atmospheric pressure is, therefore, 407.2 inches of water. Therefore,

$$\Delta P_{\text{inches of water}} = \frac{407.2_{\text{inches of water}}}{V_{test}} \times V_{(loss)}$$

Leak rate can be calculated in cubic cc/minute by the following equation:

$$\text{Leak Rate}_{\text{cc/min.}} = \frac{\Delta P_{\text{inches of water}}}{\text{Time}_{\text{min.}}} \times \frac{\text{Volume}_{\text{cc}}}{407.2_{\text{inches of water}}}$$

Likewise, if the maximum allowable leak rate is known, the ΔP can be calculated for any given leak rate in any known volume by the following equation:

$$\frac{\Delta P_{\text{inches of water}}}{\text{Time}_{\text{min.}}} = \text{Leak Rate}_{\text{cc/min.}} \times \frac{407.2_{\text{inches of water}}}{\text{Volume}_{\text{cc}}}.$$

TABLE 1

COMPONENTS	TYPICAL TEST PRESSURE RANGE	MAX. ALLOWABLE AIR LEAK RATE
Engine block - water jacket	20 PSIG	5 - 30 cc/min
Engine head - engine intake manifold Water jacket Intake passages EGR section	 20 PSIG 10 PSIG 5 PSIG	 5 - 10 cc/min 5 - 10 cc/min 10 - 50 cc/min
Engine exhaust manifold	5 PSIG	30 cc/min
Crankcase oil pan	2 - 5 PSIG	2 - 10 cc/min
Water pump	10 - 20 PSIG	5 - 15 cc/min
Combustion chambers with valves	10 - 20 PSIG	500 - 3000 cc/min
Rocker arm cover	5 - 20 PSIG	20 - 30 cc/min
Engine - final assembly Crankcase cavity Cooling jacket	 1 - 2 PSIG 10 - 20 PSIG	 50 - 100 cc/min 5 - 50 cc/min
Powertrain components Automatic transmissions (internal parts: i.e., clutches)	 10 - 20 PSIG	 500 - 2000 cc/min
Transmission worm pattern	5 - 10 PSIG	5 - 50 cc/min
Transmission case	3 - 5 PSIG	5 - 20 cc/min
Transmission final assembly	3 - 5 PSIG	15 - 30 cc/min
Modulator switch	5 - 10 PSIG	3 - 10 cc/min
Transaxles	2 - 10 PSIG	5 - 10 cc/min
Fuel systems Fuel pumps, electric and manual drive	 7 - 30 PSIG	 4 - 10 cc/min
Fuel injectors	10 - 30 PSIG	0.1 - 2 cc/min
Throttle bodies	5 - 20 PSIG	1 - 5 cc/min

COMPONENTS	TYPICAL TEST PRESSURE RANGE	MAX. ALLOWABLE AIR LEAK RATE
Coolant systems		
Radiator	10 - 30 PSIG	2 - 10 cc/min
Heater core	10 - 30 PSIG	2 - 10 cc/min
Heater valves	10 - 20 PSIG	2 - 5 cc/min
Thermostats	10 - 20 PSIG	50 - 100 cc/min
Brake components		
Master cylinder	20 - 100 PSIG	3 - 20 cc/min
Brake caliper	100 - 150 PSIG	3 - 20 cc/min
Rear brake cylinder	50 - 100 PSIG	10 - 20 cc/min
Power brake boosters - vacuum	10 - 20 PSIG	10 - 20 cc/min
Power brake boosters - hydraulic	50 - 100 PSIG	5 - 20 cc/min
Vacuum booster check valve	5 PSIG	5 - 10 cc/min
Vac. booster charcoal filter	5 PSIG	5 - 10 cc/min
Power steering components		
Power steering pump	30 - 100 PSIG	5 - 10 cc/min
Power steering gear	30 - 100 PSIG	5 - 10 cc/min
Power steering hose	50 - 100 PSIG	5 - 10 cc/min
Exhaust gas systems		
Muffler	5 - 10 PSIG	100 - 2000 cc/min
Catalytic converter	5 - 10 PSIG	100 - 2000 cc/min
Exhaust piping	5 - 10- PSIG	100 - 500 cc/min
Oxygen sensor	5 - 10 PSIG	1 - 5 cc/min
Air conditioning components		
A/C compressor	50 - 200 PSIG	10^{-2} to 10^{-4}
Evaporator	50 - 200 PSIG	10^{-2} to 10^{-4}
Condenser	50 - 200 PSIG	10^{-2} to 10^{-4}
Expansion valve	50 - 200 PSIG	10^{-2} to 10^{-4}
Accumulator	50 - 200 PSIG	10^{-2} to 10^{-4}
A/C hoses	50 - 200 PSIG	10^{-2} to 10^{-4}

A/C comp. internal valves	30 - 100 PSIG	200 to 500 cc/min

COMPONENTS	TYPICAL TEST PRESSURE RANGE	MAX. ALLOWABLE AIR LEAK RATE
Vacuum Components		
Actuators - distributor vacuum motors	10 - 20” Hg Vac	5- 20 cc/min
Climate control vacuum motors	10 - 20” Hg Vac	5 - 20 cc/min
Other vacuum actuators and components	10 - 20” Hg Vac	5 - 30 cc/min
Emission control devices		
EGR valve diaphragm	10 - 20” Hg Vac	5 - 10 cc/min
Thermo vacuum switches	10 - 20” Hg Vac	1 - 5 cc/min
Canister purge valves	0.1 - 1” Hg Vac	10 - 20 cc/min
Canisters - carbon	0.5 - 1 PSIG	5 - 10 cc/min
Electrical components		
Oil-filled ignition coil	10 - 20” Hg Vac	5 - 10 cc/min
Windshield washer pump	1 - 5 PSIG	2 - 10 cc/min
Shock absorbers		
Shock absorbers with air inflation	50 - 100 PSIG	10^{-4} to 10^{-5}
Oil reservoir	5 - 10 PSIG	5 - 10 cc/min