

Definition, Quantifying and Gauging of Tightness

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To cite this article:

Xu Changxiang. Definition, Quantifying and Gauging of Tightness. *International Journal of Energy and Power Engineering*. Special Issue: Xu's Sealing and Flowing Theories of Fluids. Vol. 5, No. 4-1, 2016, pp. 31-34. doi: 10.11648/j.ijepe.s.2016050401.14

Received: June 22, 2016; **Accepted:** June 25, 2016; **Published:** August 24, 2016

Abstract: A leakage for fluid in a pressure vessel to flow through its sealing joint to the atmosphere is just like a leakage for electric charges in a capacitor to flow through its insulator to the ground, and hence there is a sealing law for pressure vessels that is completely similar to Ohm's law, stating the leakage current I_L flowing through a sealing joint of pressure vessels is directly proportional to the pressure difference p between its two ends and inversely proportional to its leak resistance R_L , or $I_L = p/R_L$. Thus it can be known according to the sealing law that the tightness or leak resistance ($R_L = p/I_L = pt/C$) is the product of pressure p and time t expended on leaking a unit cubage of fluid through sealing joints under a fixed pressure p and can be gauged according to the sealing theorem $R_L = p(p - 0.5\Delta p)\Delta t/(\Delta pC)$, and the greater the value of $p/\Delta p$, the shorter the time required to observe, or the closer to being done at a constant pressure and temperature the test, and the more accurate the test result, where p is the test pressure, Δt is the time expended on the pressure decay from p to $(p - \Delta p)$, C is the test fluid cubage.

Keywords: Pressure Energy, Pressure's Sustainability, Sealing Law, Sealing Theorem, Tightness, Leak Resistance

0 Introduction

A traditional self-energizing rubber O-ring seal that often has no visually detectable leakage at a certain enough pressure can have a predominant application in fluid power transmitting systems, and some other traditional seals that often have some visually detectable leakage have to be used in many fluid medium conveying systems. As a result, ISO 19879 prescribes that the pass/fail criterion of seals is no visually detectable leakage for certain test pressure duration [1], and ISO 5208 classifies the tightness into 10 grades for acceptance according to no visually detectable leakage and a maximum allowable leakage current (drops or bubbles) [2]. Besides, ISO/TR 11340 classifies leakage into 6 classes regardless of influence from pressure [3]. In other words, the prior acceptance or the prior testing of tightness is so depending upon either macroscopic observation or collection and measure of leak fluids that some seals may pass that have no visually detectable leakage but can cause their vessels a definite pressure decay for pressure duration. It is because the fluid leaked out of a vessel suffers a loss from volatilization and adhesion and a change in volume from decompression that it is unscientific for the prior art to identify tightness by either macroscopic observation or collection and measure of leak fluids.

Xu's sealing theory points out that it is the most difficult for a rubber seal to create and maintain a fully leak-free joint [4]. In other words, all the other seals shall be better than a traditional rubber O-ring seal in sealing performance, or all the seals other than rubber O-rings shall be at least a seal without any visually detectable leakage, or any seal with visually detectable leakage or any seal whose sealing performance is worse than traditional rubber O-ring seals shall be unqualified. Thus it can be seen that the development of the sealing art requires that the identification of tightness shall develop from identifying some visually detectable leakage to identifying no visually detectable leakage.

Therefore, the tightness-measuring method based on either macroscopic observation or collection and measure of leak fluid not only can not satisfy the need of identifying no visually detectable leakage, but also can not accurately identify any visually detectable leakage and also has a safety risk.

1 Xu's sealing law and the definition of tightness

Xu's sealing law stating that the work (pC/I_L) done per unit of leakage current by a pressurizing piston for keeping a pressure vessel leaking at a fixed leakage current I_L or at a

fixed pressure p is called the pressure's sustainability pt of the vessel, whose magnitude is the product of pressure p and time t expended on leaking all the fluid in the vessel at a fixed pressure p , and also the product of fluid cubage C and leak resistance R_L of the vessel; i.e. the equation $pt = CR_L = a$ constant is tenable for any pressure vessel.

The pressure's sustainability of any pressure vessel is determined by a pair of intrinsic design parameters, fluid cubage C and leak resistance R_L , of the vessel, and can be measured in the length of time t expended on leaking all the fluid therein under a fixed pressure p . Because the higher the pressure p , the shorter the time t , and vice versa, it is inevitable that each product of the two pairs of parameters (C and R_L as well as p and t) that determine and quantify the pressure's sustainability of a vessel is identical, or $CR_L = pt$.

The pressure p , the leakage current I_L and the leak resistance R_L of fluid in a pressure vessel whose leakage vents to the atmosphere fully correspond to the voltage V , the leakage current I and the leak resistance R of electric charges in a capacitor whose leakage vents to the ground, and hence it can be seen from the Ohm's law ($R = V/I$) for electric capacitors that the sealing law for pressure vessels shall be $R_L = p/I_L = pt/C$.

In accordance with the law of conservation of energy, the energy released from all the pressure fluid extruded out of a pressure vessel by a pressurizing piston shall equal the work, $W = pAl = pC$, done by the piston, where p = fluid pressure of the vessel, A = cross-sectional area of the piston cylinder, l = moved distance of the piston, and C = cubage of the vessel; i.e. the pressure energy E stored in the pressure fluid in a vessel is the product of the pressure p and the cubage C of the vessel, or $E = pC$. Thus it can be seen from pressure energy $pC = (ptC)/t = I_L pt$:

- that the pressure's sustainability pt of a vessel is really the work done per unit of leakage current by a pressurizing piston for keeping the vessel leaking at a fixed pressure p , or really $pt = pC/I_L$, and
- that $pC/I_L = pt \rightarrow C(p/I_L) = pt \rightarrow CR_L = pt$, or the sealing law can also be fully proved by an equation transformation of energy.

Therefore, Xu's sealing law is the correct statement of the general pressure-sustaining law for pressure vessels.

If pressure p uses MPa as its unit and leakage current I_L uses m^3/h as its unit, it can be known in according with Xu's sealing law:

- that the tightness or leak resistance R_L ($R_L = pt/C = p/I_L$) is the pressure's sustainability pt required for a pressure vessel to leak a unit cubage of fluid through its sealing joints under a fixed pressure p , equal to the pressure p required for the vessel to leak per unit of leakage current I_L or leak a unit cubage of fluid per unit time under a fixed pressure, whose unit is $\text{Xu} = \text{MPa} \cdot \text{h} \cdot \text{m}^{-3}$; and
- that the leak conductance L_R ($L_R = 1/R_L$) is the reciprocal of leak resistance, equal to the cubage of fluid leaked out of a pressure vessel through its sealing joints per unit expenditure of pressure's sustainability, whose unit is $\text{Ux} = \text{m}^3(\text{MPa} \cdot \text{h})^{-1}$; i.e. the tightness or leak resistance R_L of a pressure vessel is the pressure's sustainability pt of a unit cubage of the pres-

sure vessel, dependent on neither its cubage nor its test pressure in magnitude, and so can be by no means identified by using either a cubage-dependent pressure duration or a pressure-dependent leakage current leaked outside it that is arbitrarily prescribed in the prior ISO standards.

Since the pressure's sustainability pt ($pt = CR_L$) of a pressure vessel with a fixed cubage C changes only with its leak resistance R_L , a like test vessel can be used to identify unlike seals by simply comparing their values of pt without needing to pay attention to specific cubage C and leak resistance R_L . For example, a like test vessel (see Fig.1) can be used to identify two seals with a like O-ring separately installed in Xu's and traditional cavities that make the O-ring have a like assembly stress or a like free extrusion radius r_a . Tests have proved that the tightness of Xu's metallic ring seal > the tightness of Xu's rubber O-ring seal > the tightness of traditional rubber O-ring seal, or tests have proved Xu's sealing theory.

Obviously, the pressure duration or the leakage current prescribed in ISO 19879, ISO 5208 and ISO/TR 11340 is not any parameter for tightness at all, and using it as an index of tightness is just like using "electric current" as "electric resistance parameter", so that all the seals of the prior art have not been in a controlled state and have caused too many accidents.

2 Xu's sealing theorem and the gauging of tightness

Xu's sealing theorem states that any fluid leakage out of a static pressure vessel will cause its pressure to decay; if Δt is the time expended on the leakage-caused pressure decay of a pressure vessel from pressure p to $(p - \Delta p)$, its pressure's sustainability $pt = p(p - 0.5\Delta p)\Delta t/\Delta p$ because the leakage during the pressure decay from p to $(p - \Delta p)$ is equivalent the leakage under a constant pressure of $(p - 0.5\Delta p)$ or because $p/\Delta p$ is the total number of subvessels of the vessel and $(p - 0.5\Delta p)\Delta t$ is the pressure's sustainability pt of a subvessel of the vessel under a constant pressure $(p - 0.5\Delta p)$ when its leakage is gauged according to pressure decay of Δp ; and obviously the greater the value of $p/\Delta p$, the shorter the time needed to observe or gauge leakage, the closer to gauging under a constant pressure and a constant temperature, the more accurate the gauged value, and the more capable of substituting p for $(p - 0.5\Delta p)$ in the pt -calculating expression.

Therefore, it can be known from Xu's sealing law what the tightness is or that the tightness or leak resistance $R_L = pt/C$; it can be known from the Xu's sealing theorem that the tightness or the leak resistance R_L of a sealing joint, $R_L = p(p - 0.5\Delta p)\Delta t/(\Delta p C)$, can be gauged by a test vessel with its cubage C known (see Fig.1); and it can be known from the resistance and conductance calculating rules that the total leak conductance of parallel sealing joints of a pressure vessel or system that vent leakage to the atmosphere equals the sum of leak conductance of each parallel joint, and the total leak resistance of serial sealing joints that vent leakage to the atmosphere equals the sum of leak resistance of each serial joint. Thus the tightness or leak resistance of a pressure vessel or system can be calculated, tested and inspected accord-

ing to the sealing joints used.

Tests have fully proved that a seal working in a linear range has a fixed leak resistance unchanging with the cubage and pressure of its test vessel, or has a leakage current I_L that is determined by the sealing law $I_L = p/R_L$ and directly proportional to the pressure between its two ends. In other words, tests according to the sealing theorem $R_L = p(p - 0.5\Delta p)\Delta t/(\Delta p C)$ have

fully proved that the sealing law ($R_L = p/I_L$) completely corresponds to Ohm's law ($R = V/I$).

Obviously, the gauging of leak resistance or tightness of a vessel or a system according to the sealing theorem $R_L = p(p - 0.5\Delta p)\Delta t/(\Delta p C)$ relates to neither macroscopic observation nor collection and measure of leak fluid, and so not only is scientific and safe but also very simple, convenient and accurate.

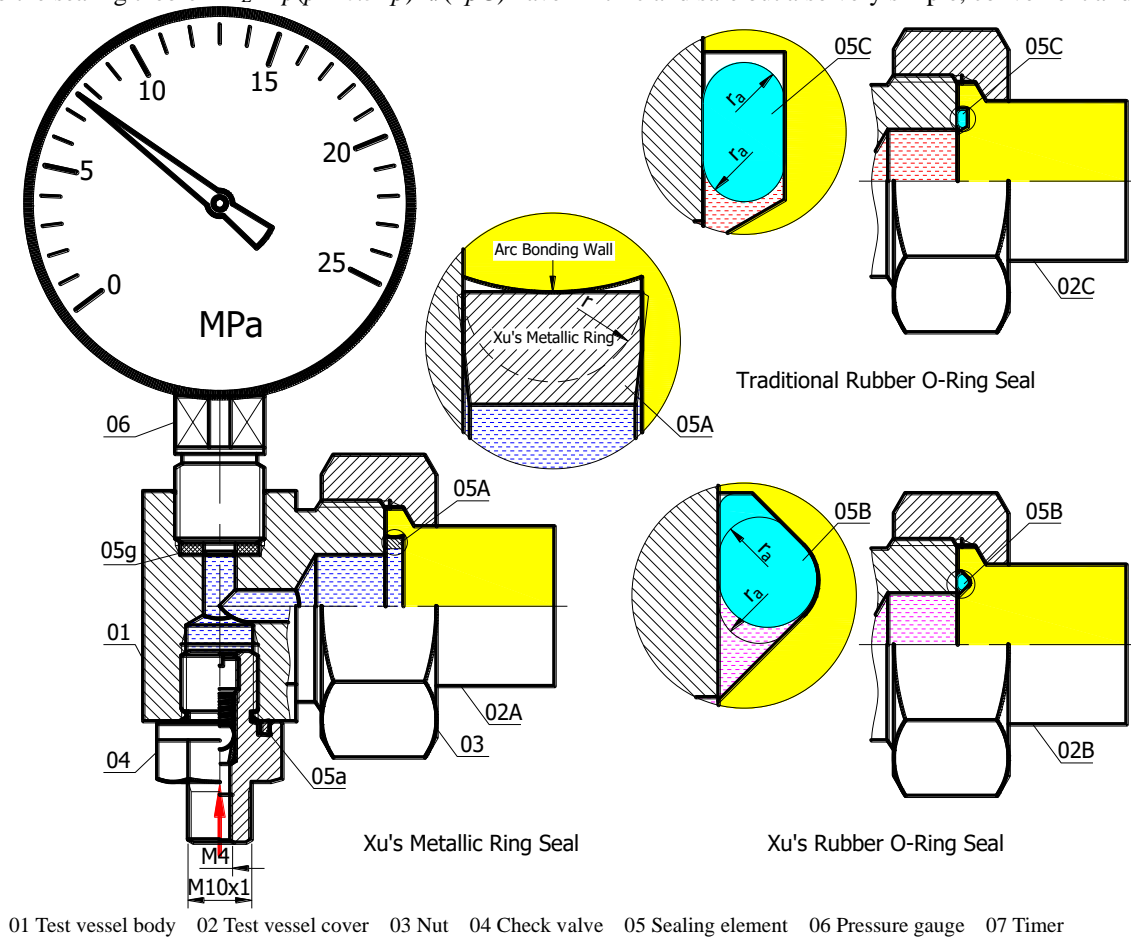


Fig.1 Tightness-Gauging Devices

3 Tightness test

A device for tightness test (see Fig.1) consists of a test vessel body (01), a test vessel cover (02), a test vessel nut (03), a check valve (04), sealing elements (05) and a pressure gauge (06). The device shown in Fig.1 is used to gauge the tightness of a Xu's metallic rectangular ring seal (05A), a Xu's rubber O-ring seal (05B) and a traditional rubber O-ring seal (05C). The structures for testing a stem seal and a piston seal can be designed in the vessel cover (02A), because the rectangular ring seal (05A) can have an infinite tightness.

The test accuracy of tightness depends first on if the check valve (04) and the sealing elements (05a and 05g) of the test device have separately a tightness far greater than that of each tested seals (05A/05B/05C), second on if the cubage of the test vessel can be accurately gauged, and then on if a test pressure decay and its time expenditure can be accurately read.

Means for ensuring that a test vessel has a tightness far greater than each tested seal is ensuring that each seal of the

test vessel has an effective sealing stress absolutely greater than the test pressure. A self-energizing PTFE ring, a self-energizing metallic ring and a spherical wedge disc check valve can have an effective sealing stress absolutely greater than the test pressure.

For the gauging of pressure's sustainability p_t , using air as test fluid is more convenient than using water, and for the gauging of cubage of a test vessel, using water as test fluid is only feasible. Hence, it is better first to use pure water and a sealing element with a median deviation to gauge the cubage and the nominal pressure's sustainability p_t , and then to use air and a sealing element with a limit deviation to gauge the limit pressure's sustainability p_t . The cubage of a test vessel is the ratio of the mass to the density of pressure water in the test vessel, and so it is required to separately measure the total weight of the test device with the full pressure water and without any water. To enable test water to fully fill the test vessel or to expel all the air from the test vessel, it is necessary to have the check valve (04) set for its decompressing

state by a decompressing screw (07) and to have the test vessel filled with test water when the valve (04) is mounted (see Fig.2a). To finish a test within a time as short as possible or by a division of pressure decay as small as possible, it shall be used a pressure gauge whose resolution is as high as possible. To have an accurate reading of one division of pressure decay, it is better to read it by having the observing start pressure p

just set for a mark line. For example, as shown in Fig.2b, first pressurize the test fluid to pressure $p = 10^+$, which is slightly higher than the observing start pressure 10, then set the pressure just for the mark line of 10 by the screw (07) before observing is ready, and last observe the time expended on the pressure decay from 10 to 9. Obviously, it can increase the measuring accurateness to develop or use a digital gauge.

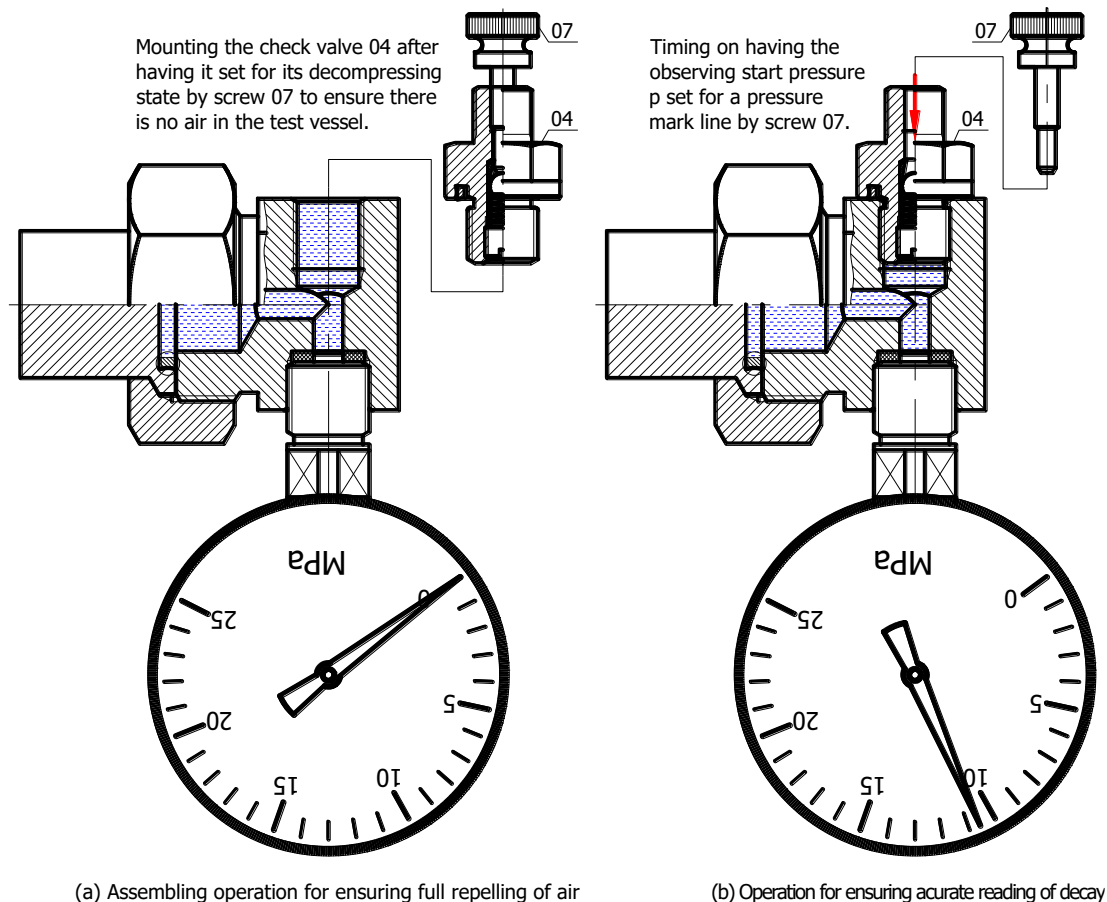


Fig.2 Key Operations in Tightness Tests

4 Conclusions

It is imaginable that a total tightness or leak resistance used as an acceptance and supervision criterion of a pressure system can be found out according to each leak resistance of joints or pressure vessels used in the system, if standards can prescribe a passing leak resistance for every seal and every pressure vessel and manufactures can also provide an actual leak resistance for every pressure vessel. Thus all the pressure vessels all over the world will be under a fully controlled condition and far away from safe accidents, and will also decrease a great deal of pollution and loss caused by leakage, if every pressure system or every independent sub-system can be examined at regular intervals on its leak resistance, for example, if a gas tank and a user's gas pipe system can be examined once a year on its leak resistance, and if a pipe system in spacecrafts, aircrafts, warships and vehicles can be examined for a certain journey on its leak resistance.

Note: This paper was initially published in Chinese magazine of Petro-Chemical Equipment, 2014, Volume 43 (3): 11-14.

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