LEAK TESTING OF PRODUCTS UNDER TRANSIENT CONDITION.

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Abstract: At use of a static mode of a product leak testing approach on a stationary level can occupy long time. It is offered two ways of decision not waiting the ending of transients. The first way consists in normalizing of the intermediate value appropriate to leak tightness norm. The second - in the accelerated approach to a balance point with using of the accumulation of trace gas. At the tightness control of any device or product with use of the test chamber of big volume (some hundreds liters) by modern leak-detector, for example Varian-948, and also when high sensitivity of the control is required, they apply a *static mode* of testing and a *mode of accumulation*. At the static mode leak detector is connected to evacuated chamber with tested products and wait a certain period of time for achievement of an equilibrium condition, when indicated signal would correspond to flow rate of gas flowing into the chamber. However, waiting of equilibrium becoming can be too long for industrial using of this mode. Another way of control can be suggested – during transition period before becoming of equilibrium.
A formula for leak flow, shown by a leak detector during transient (for static state of test system), can be deduced:

$$Q_{LT} = Q_N[1-\exp(-\frac{S_0}{V}t)] - S_0 p_l \exp(-\frac{S_0}{V}t)\,, \tag{1}$$

where Q_{LT} - leakage, shown by detector of test system, Q_N - normal leakage of tested product, S_0 - speed of pumping of leak detector, V - volume of test chamber, p_l - limiting of pressure of detector pump.
Three way of leak testing in transient regime can be regarded with using this expression:
Quasistatic regime of testing, when they execute reading of leak detector at 0,9T, where T - transient time, *(t<0,9T),* condition of quality control is

$$Q_{LT} \le Q_N. \tag{2}$$

Current transient regime of testing, when they execute reading of leak detector at any time *t,* condition of quality control is:

$$Q_{LT} \le Q_N[1-\exp(-\frac{S_0}{V}t)] - S_0 p_l \exp(-\frac{S_0}{V}t) \tag{3}$$

Transient regime of testing with threshold, when they execute reading of leak detector after time interval of T_{test}, condition of quality control is:

$$Q_{LT} \le Q_N[1-\exp(-\frac{S_0}{V}T_{test})] - S_0 p_l \exp(-\frac{S_0}{V}T_{test}) \tag{4}$$

A way of leak-testing with accumulation of probe gas is under consideration at the report also. This way is a method both an acceleration of transient and increasing of sensitivity of testing.
Mentioned ways of leak-testing were approved during developing of leakage control process of nuclear fuel for nuclear power plant.

Introduction: The leak testing of big-size devices or products in a vacuum chamber using the mass-spectrometer leak detector goes under conditions, when the probability of parasitic leakage occurrence is great - evaporation, decomposition of organic pollution, surface leakage of equipment and products at increased temperatures, if it is used. Therefore modern leak detectors with high selectivity, for example with a counterflow mode of operation, are used in this case. Thus sensitivity of the control can be reduced [1].
In such cases two ways of the control are using – static control (test chamber is pumping out by leak detector only) and static control with accumulation. A leak detector shows true leak flow under the static control and much more with accumulation. Moreover, last way can be used for acceleration of coming to equilibrium state of static control mode.
Other methods of facilitating of control process, which not need equilibrium state are discussed in the paper also. They are based on a principle of intermediate criterion.
Results: In a static stationary mode of operation of leak-testing system, when allowable leak from tested devices is much greater, then other gas flows in the test chamber and speed of pumping is much more conductivity of pipelines, expression [2] is fair:

$$Q_N = S_0 p_E\,, \tag{1}$$

where Q_N - the norm of device tightness, S_0 - speed of pumping out of the system. p_E - equilibrium pressure in the system

All leakage flows through leak-tester. Calibrated by a standard leak in the same conditions, it rather precisely defines product leakage.

For pumping out of test chamber with volume of hundreds of liters auxiliary vacuum system is used. Due to the differential flow, a pressure in the system is changeable. To measure a device leakage, they cut off auxiliary vacuum system and connect leak-tester, which has smaller speed of pumping out. Products having leakage raise pressure at the chamber.

Let the device leakage be equal to normal value Q_N and difference of device leakage and flow of pumping out be named as *differential flow*, Q_D:

$$Q_D = Q_N - Q_M = Q_N - S_0(p_l - p_E) \quad (2)$$

The differential flow raises a pressure in the system from limiting p_l. to equilibrium p_E. Transient lasts long time and decreases of the productivity control of products. The pumping-out flow, Q, can be calculated as:

$$Q = S_0 p \quad (3)$$

where p- current pressure in the system,

A change of p during little period of time dt equals:

$$dp = \frac{Q_D}{V} dt = \frac{Q_N - Q}{V} dt = \frac{Q_N - S_0 p}{V} dt \quad (4)$$

Let us introduce new variable ($Q_н$-S_0p) and take its differential:

$$d(Q_N - S_0 p) = -S_0 dp\,, \quad (5)$$

from here:

$$dp = -\frac{d(Q_н - S_0 p)}{S_0} \quad (6)$$

Substituting the formula (6) at the expression (4) and separating variables, we can receive:

$$-\frac{d(Q_N - S_0 p)}{S_0} = \frac{(Q_N - S_0 p)}{V} dt\,,$$

$$\frac{d(Q_N - S_0 p)}{(Q_N - S_0 p)} = -\frac{S_0}{V} dt \quad (7)$$

Integrating the right and left part of the equation (7) we shall have:

$$\ln(Q_N - S_0 p) = -\frac{S_0}{V} t + C \quad (8)$$

Substituting initial data $t_0 = 0; p_0 = p_l$, we shall found C:

$$C = \ln(Q_N - S_0 p_l) \quad (9)$$

Let's substitute (9) at (8):

$$\ln(Q_N - S_0 p) = -\frac{S_0}{V} t + \ln(Q_N - S_0 p_l) \quad (10)$$

After transforming and potentiating of the right and left part of the equation (10) we shall receive:

$$Q_N - S_0 p = (Q_N - S_0 p_l)\exp(-\frac{S_0}{V} t) \quad (11)$$

Continuing transformations, we shall deduce expression for pressure in the system during transient (12):

$$S_0 p = Q_N - (Q_N - S_0 p_l)\exp(-\frac{S_0}{V} t) \quad (12)$$

$$p = \frac{Q_N}{S_0} - (\frac{Q_N}{S_0} - p_l)\exp(-\frac{S_0}{V} t)$$

$$p = \frac{Q_N}{S_0} - \frac{Q_N}{S_0}\exp(-\frac{S_0}{V} t) - p_l \exp(-\frac{S_0}{V} t)$$

$$p = \frac{Q_N}{S_0}[1 - \exp(-\frac{S_0}{V}t)] - p_l \exp(-\frac{S_0}{V}t) \tag{13}$$

According to (3) the flow, which leak-detector will show during a transition period, will be equal:

$$Q_M = S_0 p = Q_N[1 - \exp(-\frac{S_0}{V}t)] - S_0 p_l \exp(-\frac{S_0}{V}t) \tag{14}$$

Let's analyze the received expression for two extreme cases. When $t=0$, we have in system the initial pressure received by auxiliary system of pumping out, when $t = \infty$, we have an equilibrium condition and pressure:

$$t = 0; p = p_l \qquad Q_M = S_0 p_l \tag{15}$$

$$t = \infty; p = p_E = \frac{Q_N}{S_0} \qquad t = \infty; Q_M = Q_N \tag{16}$$

After certain period of time, the pumped out flow should be equal practically to a leakage flow from a product and pressure becomes be stabilized. Leak detector shows the same flow as leakage. However, waiting of equilibrium becoming can be too long for industrial using of this mode.

As background flows are small, it is possible to fix leakage from a product at earlier stage of transient in conformity with the equation (13). In such context it can be introduced a intermediate norm for a tested product on the given installation.

One way of transient shortening is cutting of last, most long, part. This way of control is named *quasistatic regime of testing*. Another way - introducing of *intermediate criterion*. Last way has two modes of fulfillment: *transient regime of testing with current criterion* and *transient regime of testing with threshold criterion.* Now, about these regimes of testing in detail.

Quasistatic regime of testing. A value, indicated by leak detector is read, when speed of signal growing is less, then $0{,}9 Q_N / T_{0,9}$, where $T_{0,9}$ - period of time, during which a value from normal flow increases to $0{,}9 Q_N$.

Transient regime of testing with current criterion. A value, indicated by leak detector, is read at any time t. The current criterion of quality is:

$$Q_{LT} \le Q_N[1 - \exp(-\frac{S_0}{V}t)] - S_0 p_l \exp(-\frac{S_0}{V}t) \tag{17}$$

Transient regime of testing with threshold criterion. A value, indicated by leak detector, is read at special moment of time T_{test}. The threshold criterion of quality is:

$$Q_{LT} \le Q_N[1 - \exp(-\frac{S_0}{V}T_{test})] - S_0 p_l \exp(-\frac{S_0}{V}T_{test}) \tag{18}$$

It is reasonable to mention another ways of acceleration of control time– using accumulation of probe gas; this way is way of increasing of a testing sensitivity also.

Static transient regime of testing with accumulation of probe gas. The regime is carry out by cutoff the measuring chamber after its pumping auxiliary means up to limiting pressure p_l.

Mode carry out by cutting of the measuring chamber after pumping out by auxiliary means up to limiting pressure p_l.

Increasing of partial pressure of probe gas in the chamber occurs only due to leakage from a product proportionally of time.

If after the period of accumulation Δt there was an increase of pressure in the chamber on size Δp it means, that the product has the leakage, Q_p, equal:

$$Q_p = V\frac{\Delta p}{\Delta t} \tag{19}$$

The indication of leak-test from a product with any leakage, Q_p, after the period of accumulation $\Delta t = T_{ac.}$ will be equal:

$$Q_{LT}^{(p)}\Big|_{T_{ac}} = KQ_pT_{ac}, \tag{20}$$

The indication of leak-test from a normal leakage, Q_N, after the same period of accumulation $T_{ac.}$ will be equal:

$$Q_{LT}^{(N)}\Big|_{T_{ac}} = KQ_NT_{ac}, \tag{21}$$

As the criterion of quality of a product is the condition:

$$Q_p \le Q_N\,, \tag{22}$$

that, substituting in a condition (22) expressions (20) and (21), we shall receive a condition of quality for mode with accumulation:

$$\frac{Q_{LT}^{(p)}\Big|_{T_{ac}}}{K\Delta t} \le \frac{Q_{LT}^{(N)}\Big|_{T_{ac}}}{K\Delta t}\,, \tag{23}$$

$$Q_{LT}^{(p)}\Big|_{T_{ac}} \le Q_{LT}^{(N)}\Big|_{T_{ac}} \tag{24}$$

From expressions (24) it can be seen that criterion of quality (24) does not depend on sensitivity of installation K and time of accumulation.

Mentioned ways of leak-testing were approved for leak-testing process of nuclear fuel for nuclear power plant.

Discussion: Control of leak tightness of product by mass-spectrometry method in test chamber with big volume must be done on control installation with high selectivity and sensitivity.

The leak-testers, working at countrflow regime, have high selectivity and not high sensitivity.

High sensitivity have mode of tight control in the static regime of testing and static regime with accumulation.

For acceleration of equilibrium state becoming of control installation can be used mode of accumulation.

The mode of accumulation can be used also as special regime of control if should introduce intermediate criterion of quality.

Conclusions: 1. The equation for the gas flows in measuring system based on surface gassing and leakage from products is deduced for test regime election.

2. Some modes of tightness control of industry products are offered with use of the deduced ratio. They are_quasistatic regime, transient regime of testing with current criterion, transient regime of testing with threshold criterion, static transient regime of testing with accumulation of probe gas.

References:

1. Rosanov S.L., Pavlov V.A. Estimation of leak detector technical level. “Vacuum technique and technology”, v.11, №2, 2001.

2. Rosanov L.N. Vacuum technique. M., High school, 1990.