OPTIMAL SCHEMES AND METHODS OF DETECTING PLACES OF LEAK

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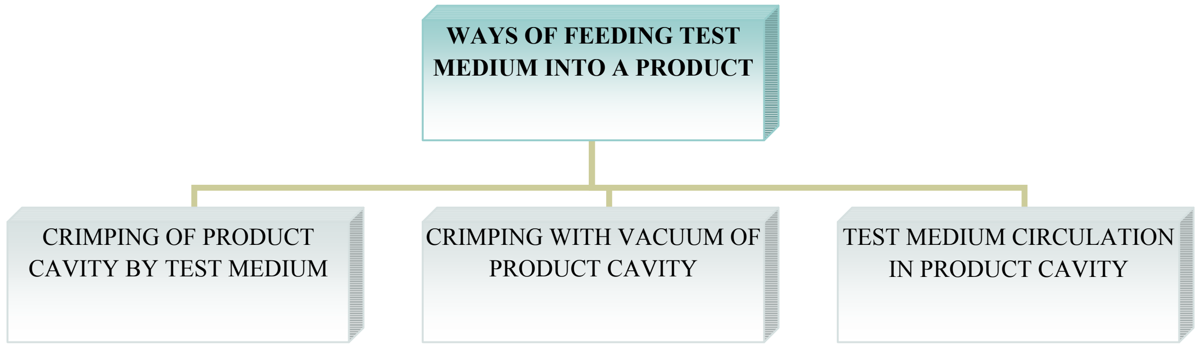
Tightness of manufacturing equipment, vessels, pipelines, armature and many other products is one of the main characteristics of their quality. The most widespread reason of products leakage is through defects of the second group formed as a result of brazing or welding of assembly unit details. The control of products tightness is made for the purpose of total estimation of products leakage or detecting places of leaks. More often leak place is detected in large-sized products. Detection of leaks places by gas-analytical method is carried out with the help of probe method, or the product surface blowing by trial gas. The blowing method assumes pumping out of the crank chamber of the product, but for some products this operation is impracticable because of insufficient rigidity of design. This method has low productivity and accuracy of detecting places of leak. That is why in practice the probe method is used more often for detecting leaks in large-sized products. The essence of this method is that trial gas is fed under pressure into the product. Because of differential pressure gas overflows through a leak channel and forms a concentration field over the product surface. Then scanning by the probe of the product surface is held for the purpose of finding out a zone of heightened trial gas concentration which helps to find the leak location. Detection of leaks places refers to labour-intensive and economically cost operations in a production cycle. As detection of leaks places is made in manual mode, possibility of errors of the first and second sort is not expelled in the course of the control. Hence, creation of automated installations for detecting leaks places is nowadays an actual problem.

Methodical maintenance of the principle of designing installations for total estimation of products leakage is presented widely enough in publications. At the same time, there is no necessary systematized information for creation of highly effective installations capable to fix the leak position.

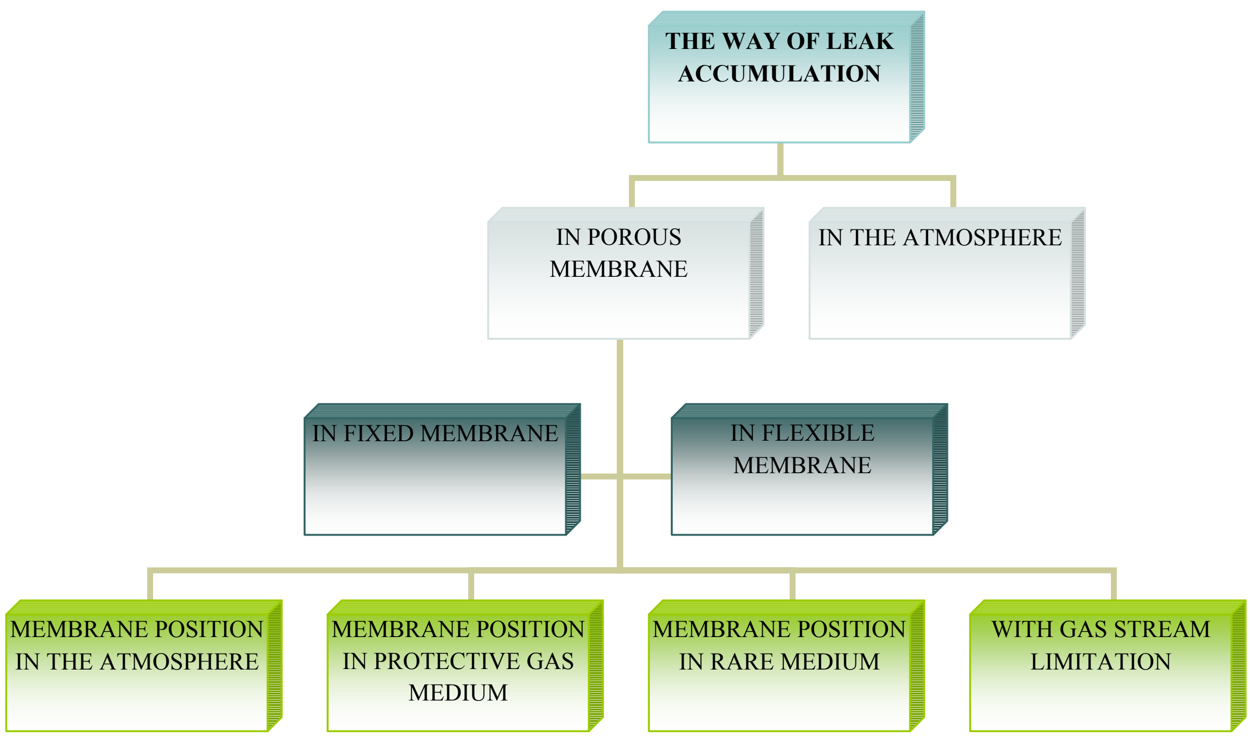
Specificity of the controllable product design, choice of the way of receiving primary flaw-detection information and also production engineering define various approaches of choosing optimal methods, circuitry at the stage of working out an installation for detecting places of leaks. To systematize information in the field of optimal schemes and methods of detecting leaks by the probe method their classification has been developed. For this purpose it is expedient to present the installation in constructive-modular aspect. The installation includes functional modules with methods and circuitry at their basis. These modules are: the module of product crimping by the control medium, the module of formation of a trial gas leak concentration field, the scanning module, the block of the analyzed sample selection, the block of the analyzed sample transportation to the leak detector, the block of preprocessing flaw-detection information (leak detector), the block of reprocessing flaw-detection information.

Pic.1 shows ways of crimping a product by test medium which is carried out by trial gas injection in the product cavity. For the purpose of receiving the heightened trial gas concentration the product cavity is preliminary vacuumized and then trial gas is fed. If the product has stagnation zones in the form of partitions it is necessary to organize test medium circulation providing test medium stream through the stagnation zones. Circulation will expel the process of trial and ballast gas exfoliation. To provide reliability of control the system of registration and regulation of trial gas concentration in the test medium is switched on to the block of test medium crimping.



Pic.1. The way of product crimping by test medium

Correct choice of the way of forming a concentration field of trial gas leak has great value for raising the efficiency of detecting leak places. As it is shown in pic.2, accumulation of leak in the form of a concentration field can take place directly in the atmosphere, but this method is ineffective owing to trial gas dilution by ambient air streams. The given method can be recommended for revealing local sections (junctions of soldered joints, detachable joints and other desk-size elements of constructions).

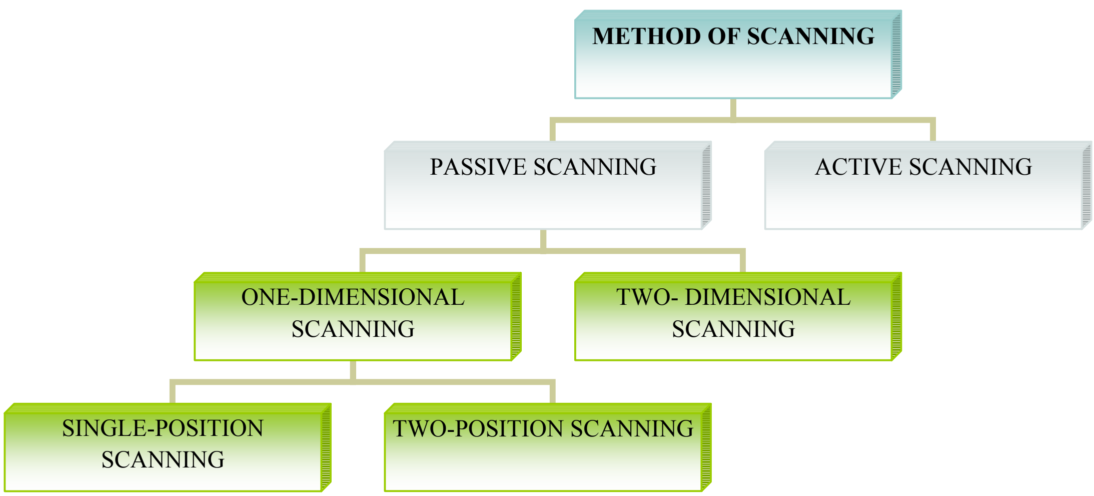


Pic.2. The way of forming a concentration field of trial gas leak

For the control of weld seams with big extent occurring in large-sized products, it is expedient to use porous membranes for accumulation of trial gas leak. The membrane simultaneously carries out functions of leak storage area and protective medium of a trial gas concentration field from ambient air streams influence. For this purpose the membrane is placed over the controllable surface. The membrane can be in quiescent state as to the controllable surface or move together with a sampler. The analyzed sample is selected from the membrane or from its surface. The trial gas concentration field can be also formed in the process of removing the membrane regarding the controllable surface. The sampler moves simultaneously with the membrane. Preference should be given to the method with the fixed membrane, high efficiency and accuracy of the control are attained in this case. If the weld seam does not have rectilinear form the fixed membrane application will lead to the decrease in efficiency of its use. For the control of twisting weld seams with small rounding radii it is better to prefer the method of leak accumulation in the flexible membrane as it is easier realized mechanically.

The way of affecting the membrane planes defines the character of the concentration field distribution in its pores because of the influence of boundary conditions change. As to the conditions of affecting the membrane planes the way of trial gas leak accumulation in the porous membrane can be divided into four aspects. If the trial gas presented in the atmosphere does not limit the threshold of sensivity the membrane can be placed in ambient air environment. The threshold of sensivity is restricted to a fraction of a background signal which is in big extent caused by the presence of trial gas on the position of products test. To eliminate this deficiency it is necessary to carry out the product control in the protective gas environment, it means that the membrane surface should be blown by gas that does not contain the trial one. Protective gas streams do not dilute trial gas leak as the zone of leak formation is protected by the membrane porous structure. If it is not possible to feed trial gas overpressure to the product and to create differential pressure on a wall of the controllable installation it is necessary to create rarefaction in the zone of the membrane arrangement. It is possible to raise control sensitivity by disposing the film made of gas-proof material over the overhead membrane plane.

The method of probe scanning is presented in pic.3



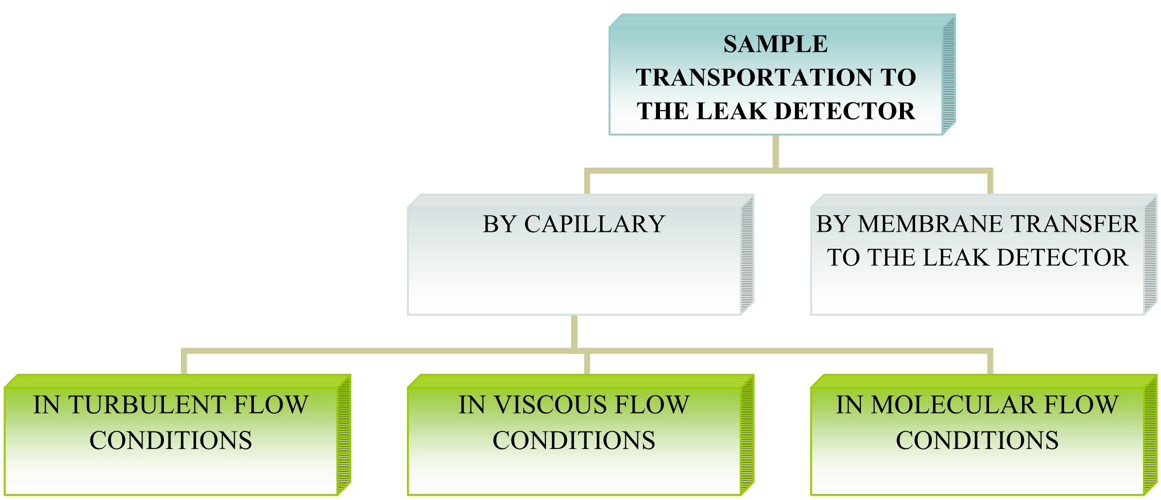
Pic.3. The method of probe scanning

The method of active scanning foresees feedback between the device moving the probe and the block of flaw-detection signal preprocessing. As a result the probe driving direction is corrected by an analog signal from the leak detector so that the probe moves in the direction of increase in trial gas concentration. When maximum concentration is achieved there is fixing of leak arrangement coordinate. The given method has pinpoint accuracy, but low productivity of leaks localization. This method is used by operators in manual mode of leaks search. In the method of passive scanning the probe moves along the reference trajectory. Two-dimensional scanning assumes reception of source flaw-detection information, that is distribution of the trial gas concentration field over the controllable product surface. At the stage of reprocessing flaw-detection information coordinates of leaks places and their stream magnitude are detected on a three-dimensional file. One-dimensional scanning assumes linear sampler motion along a weld seam. If there is leak in a product flaw-detection signal in the form of a peak appears on the exit of a block of preprocessing flaw-detection information. Reprocessing of flaw-detection information has two stages. The first stage is flaw-detection signal formalization by detecting its characteristics. At the second stage conformity of results of flaw-detection signal formalization with the coordinates of leak places is installed.

If leak detector sensitivity allows to register leaks at a distance equal to the weld seam width single-position scanning is used, it means that the probe passes one time along the weld seam; it is placed on the left or on the right concerning the control zone that includes the width of the weld seam and weld affected zones. Otherwise two-position scanning should be used when two samplers are used moving in parallel along the weld seam, but displaced in their driving direction. As a result, from the exit of the block of preprocessing flaw-detection information two signals are fed in the form of the peak into the reprocessing block from the same leak. They can help to find out leak place, both in samplers driving direction and in broadside direction regarding the samplers path. Trial gas from the membrane can be selected (pic.4), using convective or diffusion transfer mechanisms.

Pic.4. The method of the analyzed sample selection from the membrane

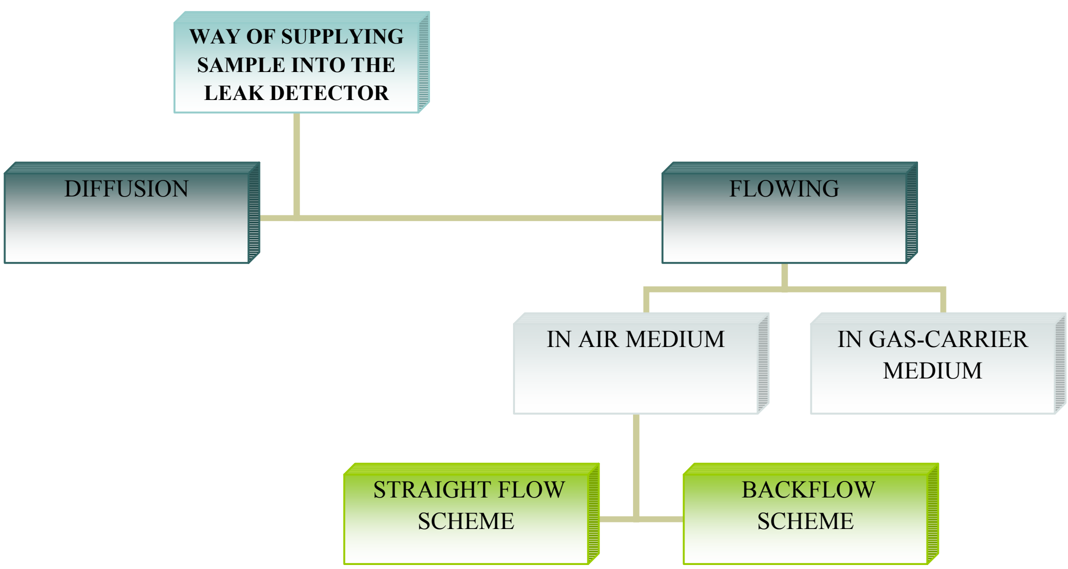
The design of a diffusion sampler element can be fulfilled in the form of a membrane having selective carrying capacity in relation to trial gas. Selective hollow fibers have more developed surface, that is why their usage as sampler elements allows to increase sensitivity of the control as trial gas from the area of concentration field formation arrives at the block of the analyzed sample transportation with heightened concentration.



Pic.5. The way of the analyzed sample transportation to the leak detector

One of the disadvantages is that sample selection occurs from the surface or volume, not in a point, that reduces accuracy of leaks localization. If sample selection occurs through a capillary hole or a butterfly governor such selection of the analyzed sample should be regarded as convective mechanism. Selection of the analyzed sample through the butterfly governor allows to fix the leaks position more precisely as local sample selection takes place. If sample selection is made through a leak valve forming small stream and its transportation occurs along a hose which end is connected to a high-vacuum chamber molecular conditions of sample flow will take place in this case. For capillaries with diameter 0.1 mm and length 5 m turbulent conditions of the analyzed sample flow are possible. Transportation of the analyzed sample from the product to the leak detector can be carried out by the membrane transfer in which pores there is trial gas leak. Then the zone of the heightened trial gas concentration is detected in the membrane; this zone helps to find leak place.

Pic.6 shows ways of supplying the analyzed sample into the leak detector. It is known that detector cells happen to be flowing and diffusion. In flowing cells the gas stream runs through a sensing element. They provide speed, but are sensitive to the change of gas stream speed. As a result, the threshold of sensivity decreases. Diffusion cells have more stable indications, but they are inertial. The analyzed sample is fed into the cell by air or other gas-carrier which provides hum level decrease. The listed characteristics refer to katharometric and electron-capture methods of flaw-detection signal preprocessing. Mass-spectrometric inspection method provides two schemes of supplying the analyzed sample into the leak detector. Straight flow scheme assumes supply of the analyzed sample into a high-vacuum part of the mass-spectrometric leak detector, providing high-sensitivity tests of a product.



Pic.6. The way of supplying the analyzed sample into the leak detector

In the conditions of high gas load the backflow method creates a tenfold win in sensitivity in comparison with the straight flow scheme as the analyzed sample is fed into forevacuum leak detector area. Turbo-molecular vacuum pump of type BMH-150M was applied as the means of high-vacuum roll-out of the mass-spectrometric chamber; this pump has the following basic characteristics: rapidity of operation on dry air, $170\cdot10^{-3}$ m^3/s; ultimate vacuum, $6.65\cdot10^{-7}$ Pa; cylinder barrel promptness 100 – 500 times per second.

The process of trial gas transfer by capillary can be presented by the equation of convective diffusion:

$$\frac{\partial C}{\partial t} + V\frac{\partial C}{\partial \xi} = D_2\frac{\partial^2 C}{\partial \xi^2};$$

where $D_2 = \frac{r^2 V}{48D} + D$ - diffusion constant in the capillary, D - molecular trial gas diffusion constant, r - capillary radius, $V = \frac{P}{\pi r}$ - stream speed in the capillary, P - power of the leak detector pump, ξ - capillary length. Boundary conditions on the entry to the capillary are defined by the function $f(t)$ describing trial gas concentration magnitude taking into account an averaged portion of the analyzed sample. The solution will be:

$$C(\xi,t) = \frac{\xi}{\sqrt{\pi D_2}}\exp\left(\frac{V\xi}{2D_2}\right)\int_0^t f(\tau)\frac{\exp\left(-\frac{\xi^2}{4D_2(t-\tau)} - \frac{V^2(t-\tau)}{4D_2}\right)}{(t-\tau)^{\frac{3}{2}}}d\tau.$$

The solution depends on dimensionless characteristic of the diffusion: $\chi = \frac{D_2\tau}{L^2}$, where L is the capillary length. In air speed bracket of gas stream from 0 to $\sqrt{192}\frac{D}{d_к}$ where $d_к$ is the capillary diameter the character of the capillary current is determined by molecular diffusion, then Taylor diffusion prevails. For devices of leaks localization where the transport capillary diameter is $3\cdot10^{-4}$ m, the length is 3 m and $\chi = 10^{-4}$, the signal dispersion on the exit from the capillary is practically not shown up. Hence, it is possible to consider the transport capillary a structural link with ideal replacement, and in the model it is necessary to consider only the time of pure delay.

Formalization of flaw-detection signal can be carried out by analogy with the description of distribution curves used in probability theory on the basis of detecting central moments of the n- th order:

$$M_n = \frac{1}{M_0}\int(t - M_1)X(t)dt,$$

Where t - current time; $X(t)$ – flaw-detection signal.

Integration limits are installed judging by the sizes of the control surface of the weld seam or by exceeding the first flaw-detection signal derivative time in relation to a background signal derivative.

The initial zero moment characterizes the area of the flaw-detection signal:

$$M_0 = \int X(t)dt.$$

The first moment points at the time of signal emersion, it helps to detect the leak place on a path of the probe motion taking transport delay into account:

$$M_1 = \frac{1}{M_0} \int tX(t)dt$$
.

The second central moment characterizes the peak width. Coefficient of the peak skewness is expressed through the third central moment. Sharpness of the peak is determined by an excessive act which helps to fix leaks characteristics at superposition of trial gas concentration fields from two leaks close to each other. Noise immunity of the concentration field of trial gas leak by means of porous membranes expels inaccuracy of measurements of the leak place, but the fault is also caused by background signal fluctuation by the leak detector measuring system, as a result, false peaks are formed. The filtering of false peak on the exit from the leak detector is made on value part of characteristics of its formalization. As the formalized characteristics from the leak have determined character they are mutually casual whereas characteristics from the false peak have random nature. Probability of the fact that all the formalized characteristics from the false peak will coincide with the flaw-detection peak characteristics is very small. Hence, the use of the method of detecting leak by the formalized characteristics contributes to the raise of metrological characteristics of a device for leak detecting.

The leak place towards the sampler driving direction is estimated by the first moment or when there is a change of a sign of the first curried function of the flaw-detection signal by time from plus to minus. The distance from the leak to the scanning line is appraised from relations of the area to the altitude of the flaw-detection signal peak.