TIGHTNESS MONITORING CAMERA FOR CRITICAL PARTS OF RURAL TECHNOLOGICAL AND SCIENTIFIC EQUIPMENT

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Abstract. There are a lot of devices, including rural equipment with a high level of tightness. Nowadays, a wide range of methods are used for investigation and testing: capillary, radiographic, radio wave, mass spectrometric, eddy current, surface-active substances, etc. These methods require special equipment and do not allow continuous monitoring during operation. The traditional soap solution coating can continuously monitor the tightness until drying. Thus, there is a problem in creating an easy and robust method of monitoring the tightness of the critical equipment parts during the operation. In this work, a new method for the tightness control is proposed. It is based on the principle of distributing flows in parallel piping. If the camera around a critical part is sealed, its leaks will have high aerodynamic resistance. Therefore, if a small hole (0.1-1 mm) is made in such a camera, its aerodynamic resistance will be some order smaller. Since the distribution of flows is inversely proportional to the square of the specific characteristic of aerodynamic resistance, the main outflow or inflow due to leakages in the critical part inside the camera will occur almost through this hole, which is easy to register. This camera has been used in the Laboratory of Heat-Mass Exchange in Green Structures to test gas exchange in plants. For testing the method, the fan in the test stand before final sealing is slowly accelerated until the signal appears. After that, the flow rate has been estimated using a collector. The results show a very high sensitivity. In the collector, the anemometer showed only 0.02 $m \cdot s^{-1}$. The confidence interval of the flow is 0-0.019 $m^3 \cdot h^{-1}$. However, the anemometer reading near the hole is 0.43, which is a very clear signal. The signal will be clear at the leakage of 0.0086 $m^3 \cdot h^{-1}$. The soap coating of all junctures and smoke visualisation did not show a leakage place. This allows recommending the camera for the most critical equipment parts.

Keywords: tightness, leakage, responsible equipment, hydronic system.

Introduction

Checking the tightness of elements, parts, or constructions is an integral part of the technological process in various fields of science and technology. In the work [1], the typical problematic experimental study of the heat exchange in thin pipes referred to the design of effective regenerative ventilators for rural individual living houses. In the work, the possibility of increasing precision by additional heat insulation is shown. This allows using very low flow rates without significant heat measuring uncertainty, which requires near absolute airtightness to decrease the flow metering uncertainty. The next characteristic experimental example is the research on the positive effects of vegetation layers in green structures. Today, the thermotechnical properties are investigated [2]. On the other hand, gas exchange properties are not less important. The complex solutions to increase environmental quality energy-efficiently by plants on outdoor [3] and indoor [4] green structures are shown. Nevertheless, the first research is qualitative and the second gives only the CO_2 content decrease in some phytocompositions. To perform the quantitative research for engineering calculations, a gas exchange camera is necessary. The staged experiment revealed the unprecedented airtightness requirements for such cameras, which set the direction of this work. Another example is the underground gasification of coal. In many works, including [5-9], it is shown theoretically and experimentally that the tightness is very important. Thus, there is a problem with monitoring tightness at a very high level.

The issue of tightness has long been a concern for researchers worldwide. For example, in [10], the method for testing the tightness of electric cells under mechanical load is issued. It is applicable only for models under an intensive external load. The optimisation of the tightness of the combustion chamber in a solid-fuel boiler is theoretically and practically investigated in [11], developing a new construction of the boiler. In [12], the tightness of high-pressure pipelines of heat pumps is laboratory investigated and the method for increasing it is proposed. For medical applications, the Schlieren optical method to detect leakages is used in the works [13-16], which is acceptable for high pressure/temperature differences or indicator gases only. For very tight equipment, especially for lightweight gases, in the work [17] the impregnation of microcavities is investigated theoretically by the laws of filling the cavities. The technology is proved as perspective. However, such a theoretical approach is applicable only for material improvement. In [18], a very simple technique is used for tightness control – supplying

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and metering the air to the tested volume. This principle is the basis of the door blower test for airtightness in premises [19]. This technique due to its simplicity and precision can be used for validation of other methods. This method requires intervention in the equipment, which makes it not applicable for monitoring. The work [20] proposes to replace the method with pressure difference and airflow measurements at different outdoor temperatures. This technique applies to buildings only. Tracer gases [21] are also used for airtightness checking. This method also requires intervention. Transient methods are used rarely [22-24], which are based on pressure decay differentiation during leakage after pressurising. The problem of intervention cannot be solved.

There are special methods for more complicated cases [25]. Capillary methods are based on the indicator liquid penetration into the surface defects. The radiographic method is making X-ray pictures of the tested parts. Radio wave methods register changes in the electromagnetic waves of a defect. The mass spectrometric method uses the supply of an indicator gas to the equipment and the detection of the gas by mass spectrometry. The method of eddy current defectoscopy is based on anomalies in microdefects in an alternating electromagnetic field. The method of surface-active substances is a traditional method for gas pipelines by covering the possible places of leaks with surface-active substances registering air bubbles. All of the special methods above cannot monitor the airtightness during the operation, where it is impossible to apply a specific tracer substance, etc.

The work aims to develop a fundamental solution for checking and continuously monitoring the tightness of responsible equipment parts under excess or reduced pressure separately during operation without any influence on the monitored equipment parts.

Materials and methods

The principle of sealing control is based on the known dependency of flow distribution in parallel pipes of hydronic systems using the flow share

$$\alpha = Q_2/Q_1 = (C_1/C_2)^{1/2} = K_{v1}/K_{v2}, \tag{1}$$

where Q_2 and Q_1 – flow rates in two parallel pipes, $\mathrm{m^3 \cdot s^{-1}}$;
C_1 and C_2 – specific characteristics of hydraulic resistance, $\mathrm{Pa \cdot m^{-6} \cdot s^{-2}}$ of the corresponding pipes;
K_{v1} and K_{v2} – flow factors, $\mathrm{m^3 \cdot h^{-1} \cdot bar^{-1/2}}$ of the corresponding pipes.

Let us cover a critical part of a system with overpressure or vacuum separately by a closed and sealed tightness monitoring camera (Fig. 1). The camera can be large with many joints.

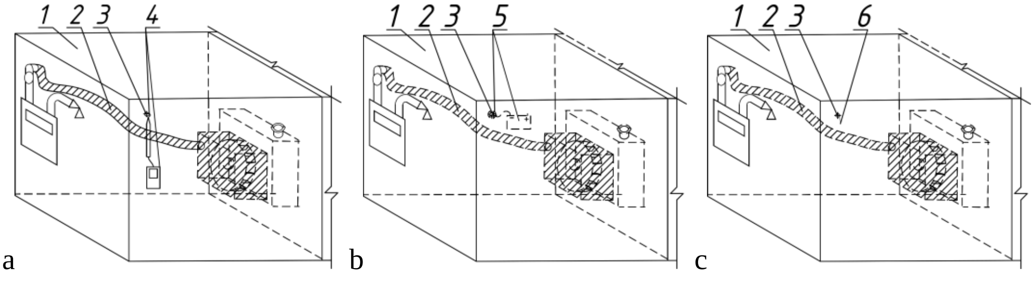

Fig. 1. **Tightness monitoring camera**: a – with thermoelectroanemometer; b – with flow meter; c – with flow indicator (a thread): 1 – camera; 2 – critical part of a system with overpressure or vacuum; 3 – hole; 4 – thermoelectroanemometer; 5 – flow meter; 6 – flow indicator (a thread)

Very small sealing defects can be unnoticeable and can be detected only by special methods. In addition, they may appear in the future. But the most important that they are very small and have great specific characteristics of hydraulic resistance or a tiny flow factor.

Let us form a hole in the camera. The hole should be reasonably small – 0.5...3 mm and so on. Its area A, $\mathrm{m^2}$, is significantly bigger than the total area of the sealing defects in any case.

The specific characteristic of hydraulic resistance and the flow factor of the hole is several orders of magnitude less and greater than the sealing defects. By equation (1) this hole lets through the most of leakage or suction of the system part. The velocity, $\mathrm{m \cdot s^{-1}}$

$$v = \alpha \cdot Q/A, \ \alpha \rightarrow 1 \tag{2}$$

The next step is to detect the flow. The most sensitive method is thermoelectrical. A sensor of a thermoelectroanemometer can be put very close to the hole (Fig. 1, a). The measurement conditions are broken because the sensor is comparable to or larger than the flow. Nevertheless, our goal is to register the fact of leakage. Thus, we cannot use a velocity unit for the device reading. We will use conventional units (c.u.) instead. The reading of the thermoelectroanemometer can be affected by surrounding flows. A flow meter with minimum resistance can be attached to the hole to avoid mistakes. It can be a 3D-printed collector – a smooth entry, better if by Bernoulli's Lemniscate. The sensor can be put inside the collector. Another way is to attach a micromanometer (Fig. 1, b) to a static pressure fitting on the collector. This way is significantly less sensible. The third way is using a flow indicator (Fig. 1, c). A very soft, thin thread can be attached above or inside the hole. This method is the simplest but the least sensible.

Laboratory testing

The tightness monitoring camera is implemented in the gas-exchange camera of the Laboratory of Heat-Mass Exchange in Green Structures. In Fig. 2, it is shown during the experiments with plants. The first section 1 is the tightness monitoring camera around the fan, air parameter measuring camera and a hose to the airflow metering device – the critical part 2.

To test the sensitivity of the tightness monitoring camera, laboratory tests have been performed on the camera in Fig. 3. Input to the fan is performed through the collector 7 of a very smooth shape, which was used as an air metering device. The diameter of the collector was measured by a calliper with a resolution of 0.05 mm. The diameter is 9.897 ± 0.058 mm. The area is $A = 7.6938 \cdot 10^{-5} \pm$ $\pm\ 0.0091 \cdot 10^{-5}$ m^2. The fan was temporarily connected through the autotransformer 8, powered by a dual-conversion stabiliser 9 (12 V power supply and inverter). The valve on the output was closed, thus the airflow through the collector was equal to the leakage.

The anemometer 4 has been installed close to the hole 3. The anemometer is a Testo 445 data logger with a hot-bulb probe Testo 0635 1049 of the diameter 3 mm and the area of midsection $7.069 \cdot 10^{-6}$ m^2, which measures the velocity $v = 0...10$ m·s^{-1}, with uncertainty $\pm\ (0.03 + 0.05\ v)$, m·s^{-1}.

Initially, the anemometer 4 showed 0.08 c.u. The autotransformer 8 was slowly increased until the reading of the anemometer 4 will change. The new value is 0.43 c.u. After that, the measurement in the collector 7 has been performed. The area of the sensor midsection occupies 9.2% of the collector. Thus, we cannot use a collector with a smaller diameter. The anemometer showed 0.02 m·s^{-1} without changing the last digit for more than one minute. Thus, the random error is out of the device range due to the very smooth shape of the collector, which cannot generate flow pulsations. The confidence interval is $w = 0...0.061$ m·s^{-1}. This reading is too low. The uncertainty is more than 100% of the measured value. Thus, it is impossible to perform tests at lower speeds. Trying it caused unstable fan operation up to stop. But the signal of the camera is very clear. Decreasing the airflow two times by the law of flow distribution by parallel branches will cause two times less reading – 0.21 c.u., which is also a very clear signal.

Results and discussion

Let us calculate the maximum possible flow, equal to the leakage. Let us assume that the sensor with the boundary layer on it displaces 10% of the collector area. Thus, the velocity is $k = 1.1$ times greater than the velocity in the empty collector.

The velocity profile in the collector is very close to uniform due to the collector shape. Using the confidence interval of the velocity w, it is possible to estimate the maximum leakage from the camera – $\max(w) \cdot k \cdot A = 5.1625 \cdot 10^{-6}$ m^3·s^{-1} or 0.019 m^3·h^{-1}. Thus, the actual leakage is in the range 0... 0.019 m^3·h^{-1}, which is comparable with the start of the membrane gas meter. At this leakage, the anemometer reading near the hole of the camera is 0.43 c.u. If the threshold is 0.2 c.u., the maximum leakage by the law of flow distribution will proportionally decrease to $5.1625 \cdot 10^{-6} \cdot 0.2/0.43 =$ $= 2.4012 \cdot 10^{-6}$ m^3·s^{-1} or 0.0086 m^3·h^{-1}. Such a low leakage can be registered by special methods, for example, mass spectrometric, but they cannot monitor an equipment part during the operation. Thus, the test of the tightness monitoring camera is successful. Less airflow cannot be checked. Anemometer is no more sensitive, and the fan stops trying less speed.

Fig. 2. **Gas exchange camera in Laboratory of Heat-Mass Exchange in Green Structures with the tightness monitoring camera, general view** (pos. – see Fig. 1)

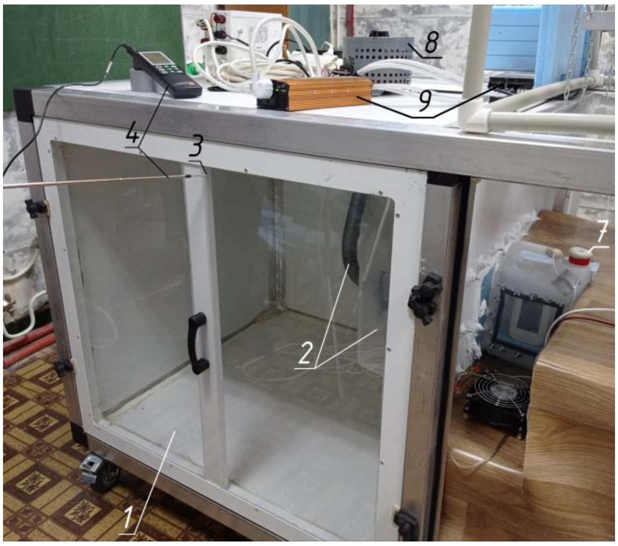

Fig. 3. **Laboratory tests of the tightness monitoring camera:** pos. 1-6 – see Fig. 1; 7 – collector for measuring the airflow; 8 – autotransformer; 9 – dual-conversion voltage stabiliser

For comparison with other methods, a soap solution was applied to all of the junctures with a length of approx. 2.3 m incl. the fan and measurement camera, and pipe connections. No bubbles were formed. The second trial is smoke visualisation. Smoke is applied to all juncture perimeters. No effect was seen. The total length of junctures is too long, and the leakage speed is too low. After removing the silicon sealant and replacing it with plasticine, the anemometer near the hole does not change the reading after starting the fan. Thus, the tightness was provided successfully. The special methods are not applied to the stand due to the pressure limitations of the plastic materials used, the possible influence of trace gases on the living plants and the impossibility of continuous monitoring by them.

The camera is recommended for wide application in different branches of science and technique for precise experimental stands, responsible equipment, etc, especially for critical rural equipment parts. We have a successful experience using the camera for gas exchange research of plants (Fig. 2) allowing too small air flows.

The scientific novelty is the research and development of the new principle of airtightness monitoring for equipment, which allows raising the precision of scientific equipment on a new level.

Conclusions

1. The tightness monitoring camera allows monitoring of too small leakages of the critical parts of the responsible equipment, especially for rural machinery.
2. Laboratory test on the limit of possibilities of the modern measuring devices shows very high camera sensitivity. At the flow less than 0.019 $m^3 \cdot h^{-1}$, we obtained a readable signal – 0.43 c.u.

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