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INVESTIGATION OF OPERATION OF AUTOMATIC RESPIRATORY VALVES

by

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INVESTIGATION OF OPERATION OF AUTOMATIC RESPIRATORY VALVES

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ABSTRACT : The article describes a new method and apparatus for determining the resistance and gas bypass of self-regulating respiratory valves, Bypass is defined as the amount of gas passing through the valve in the opposite direction during a respiratory cycle. The relationship between valve resistance and gas bypass has significance for oxygen-breathing apparatus, particularly with gravitational valves, in which too much bypass can conceivably lead to patients' hyperkapnia. Gravitational, coil and gasproof valves were tested. In the study of the gravitational valve, coincidence of theoretical and experimental values for stationary flow and sinusoidal respiratory pulse flow was found. Closing of the valve in the idle phase depends on 3 factors: (1) the vacuum required for drop of the valve, (2) valve inertia and friction, and (3) valve weight. For valves up to 3 g, the first factor proved decisive Greater valve weight at the same ventilation will result in less slippage. Coil valves and gasproof valves were found to act almost the same as the gravitational. Dependence of resistance on ventilation is a constant for gravitational valves but is a variable for coil valves. Absolute slippage values were about the same for all sizes of coil valves. Theoretical and experimental results agreed closely, and it was concluded that the slippage of a self-regulating valve of any kind can be approximately calculated if the geometric parameters and resistance to the operational conditions under study are known. The sequence of bypass determination on the universal suction apparatus is as follows: dependence of rate of suction on pressure drop, change of pressure drop in the working apparatus, mean value of pressure drop at the idle phase, mean rate of suction, time of idle stage, and dependence of valve resistance on lung ventilation. Formulas for these determinations are given. Absolute values obatined for bypass with the various valves in use showed it to be insignificant, involving no danger of hyperkapnia. For artificial lungs where valve resistance is unimportant, the gasproof valve can be recommended. Orig. art. has: 3 figures, 6 formulas and 1 table. English translation: 12 pages.

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U. S. BOARD ON GEOGRAPHIC NAMES TRANSLITERATION SYSTEM

Block	Italic	Transliteration	Block	Italic	Transliteration
А а	*А а*	A, a	Р р	*Р р*	R, r
Б б	*Б б*	B, b	С с	*С с*	S, s
В в	*В в*	V, v	Т т	*Т т*	T, t
Г г	*Г г*	G, g	У у	*У у*	U, u
Д д	*Д д*	D, d	Ф ф	*Ф ф*	F, f
Е е	*Е е*	Ye, ye; E, e*	Х х	*Х х*	Kh, kh
Ж ж	*Ж ж*	Zh, zh	Ц ц	*Ц ц*	Ts, ts
З з	*З з*	Z, z	Ч ч	*Ч ч*	Ch, ch
И и	*И и*	I, i	Ш ш	*Ш ш*	Sh, sh
Й й	*Й й*	Y, y	Щ щ	*Щ щ*	Shch, shch
К к	*К к*	K, k	Ъ ъ	*Ъ ъ*	"
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М м	*М м*	M, m	Ь ь	*Ь ь*	'
Н н	*Н н*	N, n	Э э	*Э э*	E, e
О о	*О о*	O, o	Ю ю	*Ю ю*	Yu, yu
П п	*П п*	P, p	Я я	*Я я*	Ya, ya

* ye initially, after vowels, and after ъ, ь; e elsewhere. When written as ё in Russian, transliterate as yё or ё. The use of diacritical marks is preferred, but such marks may be omitted when expediency dictates.

INVESTIGATION OF OPERATION OF AUTOMATIC RESPIRATORY VALVES

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Calculations of resistance of automatic values, which are the most widespread pneumatic distributive devices in technology and, in particular, in oxygen-respiratory equipment, are given in a number of works [2, 4, 8]. In these works are established dependences of resistance of different automatic valves on speed of gas passing through them (constant flow) and on ventilation of breathing (pulsating flow). However, in none of investigations was there revealed a dependence between resistance of valve and bypass of gas in it, but such dependence undoubtedly exists. Practice shows, for instance, that spring-loaded valves, having higher resistance than those of gravitational type, ensure smaller bypass. Gravitational valves of various weight have different resistances and bypasses.

Bypass is conditionally called that quantity of gas passed through valve during one respiratory cycle in direction opposite the working course (i.e., that in which circulatory flow passes through valve).

In circuits working without vibrations, overflows in valve devices are small and for a series of medical gas instruments and apparatuses are immaterial. However, valves, especially those of gravitational type, do not always work stably [4]. Their design and manufacture can have defects. Therefore bypasses can render influence on conditions of breathing. Magnitude of possible bypass of valves must be known in order to estimate danger of hypercapnia due to accumulation of carbon dioxide in the circulatory system of instrument or apparatus.

For checking operation of automatic valves several methods have been developed, which are described in detail in a number of works [4].

It is possible to divide conditionally bypass of valve into 2 parts – slipping and leakage. Slippage of valve is quantity of gas passed through valve in direction of its shutting during the time of shutting. Leakage is quantity of gas passed through valve after its shutting. At present during the checking of valves we usually consider that bypass is equal to leakage, i.e., slippage is equal to zero. This cannot be taken as correct, since slippage, as will be shown below, composes a considerable part of bypass, especially during forced breathing.

Method of determination of leakage is very simple. In space ahead of valve, i.e., in space from which occurs expiration of gas in working direction through slot between valve and seat (Fig. 1), there is created rarefaction with help of any sucking device (1) with receiver (5); quantity of gas passed through valve is determined with help of any flow meter (rheometer, rotameter) or, what is a more exact method, with the help of spirometer of low capacity (2),

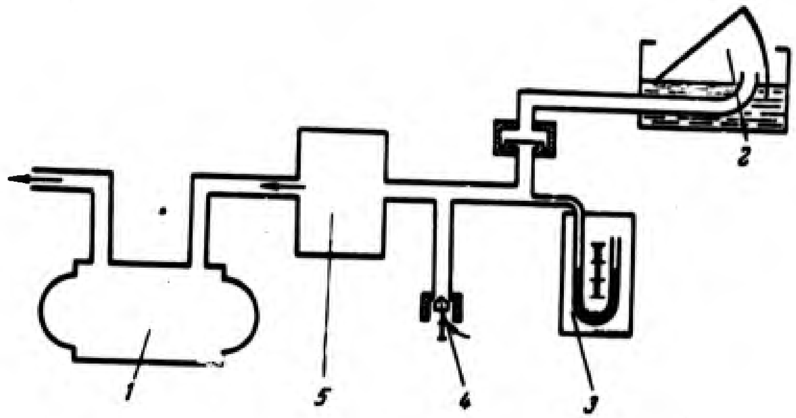

Fig. 1. Diagram of leakage installation. Explanation in text.

and rarefaction is regulated by valve (4) and is measured by manometer (3). Analogous test is conducted at excess pressure in valve space.

Sometimes rate of leakage is determined from drop of rarefaction, created in constant volume in space ahead of valve (or pressure in valve space).

A new method of separate and simultaneous determination of slippage, leakage, and resistance of automatic valves was developed at [VNIIMIiO] (ВНИИМИиО) [4].

To investigations on installation working per new method were subjected gravitational, spring-loaded, and, counterpressure automatic valves. The simplest physical picture is observed during work of the slide-type gravitational valve. Rise of valve, as was noted, is caused by appearance of pressure drop during expiration of gas through slot between slide and seat. Lift in this case does not depend on height of rise of valve and is equal to its weight. On the basis of this, there was derived a formula for height of rise of valve during steady-state operating conditions. Taking into account losses to flow friction of slot this formula has the following form:

$$h = q\sqrt{\frac{C_x \rho}{8\pi G}\cdot\frac{d_{cp}}{d}}\ \text{m}, \tag{1}$$

where q is volume velocity of gas (in m^3/s); d is diameter of seat (in m); $d_{cp} = \frac{d + d_k}{2}$; d_k is diameter of valve (in m); G is weight of valve (in kg); ρ is density of gas (in kgs^2/m^4); C_x is 1.14 [4].

For calculation of resistance from flowing around of valve (if this flowing around occurs) by cofactor there is introduced empirical coefficient, equal to $\sqrt{\frac{d_{cp}}{d}}$.

Experimental investigation [5] showed that formula (1), exact for stationary flow, is applicable also for sinusoidal pulsating flow, characteristic for breathing. Thus, if we know weight of valve, its diameter, diameter of seat, and volume velocity of gas passing through valve, we can determine, to what height it is lifted.

Lowering of valve on seat in nonworking phase can occur under the action of 3 factors, which can act simultaneously.

For creation of flow through valve in nonworking phase there first of all is required creation of rarefaction in space ahead of valve. It is formed as a result of suction of gas from under valve. Appearance of rarefaction causes pressure drop on valve, which strives to close the latter. If valve possesses low inertness and friction of it against air and guides are insignificant, the valve will move after sucking flow, during minimum rarefaction. Here, owing to the weak degree of rarefaction, flow through slot between valve and seat can be negligible. Consequently, in this case during shutting of valve volume of gas located under valve will be sucked out. Thus, slippage in this case is equal to:

$$\Delta V_1 = S \cdot h_0 - \text{m}^3, \tag{2}$$

where S is area of valve seat (in m^2); h_0 is height of rise of valve (in m).

The second factor appears in the presence of flow through the slot between valve and seat, i.e., in that case when inertness of valve and frictional forces are great; therefore the valve will lag behind the sucking flow. In this case rarefaction under valve grows and pressure drop in slot becomes sufficient to create a noticeable flow of gas. During expiration of gas through slot (in accordance with Bernoulli equation), there is created a pressure drop, which strives to close valve.

The third, constantly effective factor striving to close valve is its weight.

Experiments conducted with gravitational valves of various weight by described method confirmed the fact that for comparatively light valves (up to 3 g) the first factor is decisive.

Using formula (1), we write general expression for slippage with allowance for only the first factor:

$$\Delta V_1 = S \cdot h = 0{,}157 \cdot q \cdot \sqrt{\frac{C_{xp} \cdot d^3 \cdot d_{cp}}{G}}\ м^3, \qquad (3)$$

where q is volumetric flow rate at the moment of change of phases of respiratory cycle (in m^3/s).

On installation at the moment of change of phases, with ventilation of 15 ℓ/min, speed of gas was 0.0005 m^3/s. All experiments were made with valves having a seat diameter of 24 mm, since this diameter is recognized as the most optimum for medical respiratory instruments and apparatuses [5].

In Fig. 2a are graphically represented results of experiments with gravitational valve weighing 1.63 g, in the form of dependence

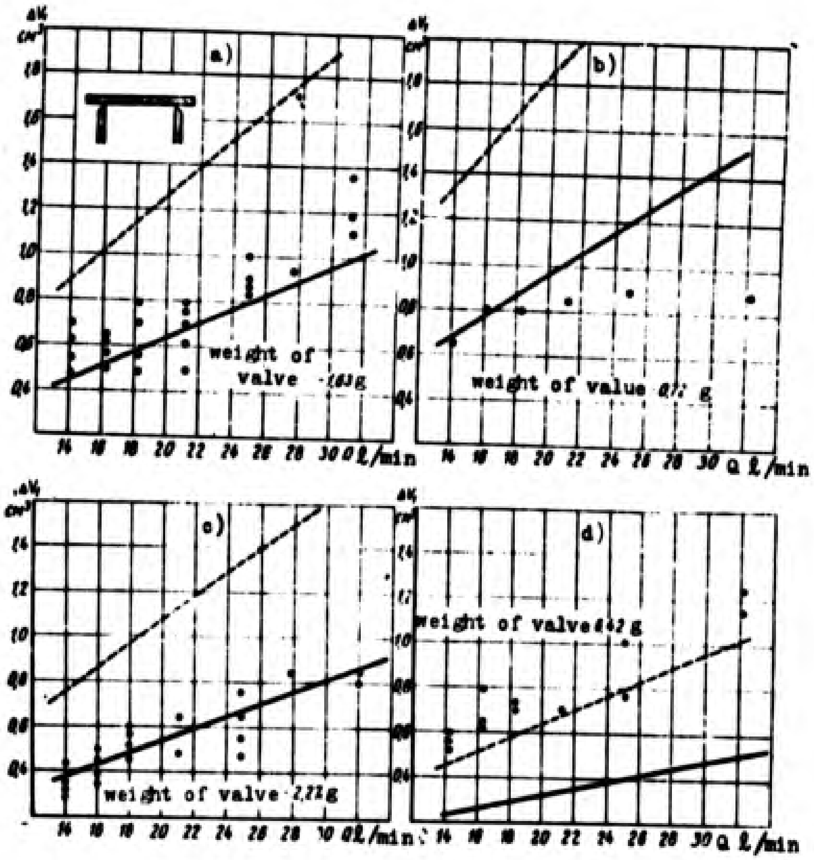

Fig. 2. Dependence of slippage on ventilation for gravitational valves of different weight. Explanation in text.

of slippage on ventilation. On the graph are 2 straight lines. One of them (solid) depicts dependence of slippage on ventilation, calculated by formula (3), i.e., theoretical dependence. From the graph it is clear that experimental points are grouped around theoretical line with certain scattering, characterizing instability of work of valve. Instability is caused by many factors, having random character: misalignment during rise and fall, friction against guides, turbulence of gas, etc. Theoretical calculation of all these factors is practically impossible. Therefore only on the basis of experiment can the conclusion be made that absolute value of instability of work of valve does not exceed ±0.3 mℓ.

Dotted line on graph depicts calculated dependence of highest possible slippage of given valve on ventilation. This dependence is calculated also by formula (3), but instead of volumetric flow rate at the time of change of phases, in this formula is substituted maximum flow rate for respiratory cycle. Maximum flow rate, as it is known from (3), for sinusoidal form of pulsating flow is equal to:

$$Q_{макс} = 4Q,$$

where Q is one minute's ventilation during breathing (in ℓ/min).

Obviously, during calculations of slippage of an actually working valve, owing to the possibility of change of phases during maximum flow rate, for high reliability one should use the formula:

$$\Delta V'_1 = 1{,}05 \cdot 10^{-5} \cdot Q \cdot \sqrt{\frac{C_{sp} \cdot d^3 \cdot d_{cp}}{G}}\ м^3. \qquad (4)$$

From formulas (3 and 4) it is clear that with increase of weight of valve for the same value of ventilation, owing to decrease of height of rise, slippage of valve decreases; and with reduction of weight, slippage is increased. This maybe seen in Fig. 2b and c, where analogous dependences are depicted for valves weighing 0.72 and 2.27 g.

Experimental curve of light valve (see Fig. 2b) has horizontal section, formed as a result of the fact that valve during rise rested on limiter of movement. Hence two important conclusions can be made.

First, if there is a limiter of movement of valve, then the highest possible slippage, aside from dependence on ventilation, is equal to height of limiter multiplied by area of valve seat. By regulating height of limiter it is possible to ensure permissible slippage for any circumstances.

Second, in case of rubbing of valve against guides during rise, which in this case become limiters of rise, slippage is constant and its magnitude is less than calculated.

Experiments conducted showed that for valves weighing at least 2.27 g the first factor is dominating. This cannot be said of heavier valves. Thus, for instance, experimental points for valve weighing 6.42 g lie above not only the calculated line, but also the line of maximum slippages (Fig. 2d).

Physical picture of work of spring-loaded automatic valve almost does not differ from analogous picture of work of gravitational valve. The difference consists in that in the last case the height of rise of valve, and consequently the magnitude of slippage, are proportional to ventilation [see formula (4)], since the closing force itself depends on height of rise of valve. Furthermore, the scheme of work of gravitational valve is fully defined – it works only in vertical position – while spring-loaded valve can work in any position (vertical, horizontal, or slanted), which is one of the main causes responsible for its application. In various working positions the closing force has different magnitude; therefore slippage will be different.

For determination of slippage in nongravitational valves it is convenient to apply calculation-experimental method. Essense of it consists in the following. Height of rise of gravitational valve, and this means slippage also, are simply related to resistance of valve. As experiments showed [4], resistance of gravitational valve is practically independent of ventilation (in interval up to 30 ℓ/min) and is approximately equal to weight of valve divided by its area. Therefore it is possible to give formula (4) more general form:

$$\Delta V_1 = 1.19\cdot 10^{-6}\cdot Q\sqrt{\frac{C_{x\rho}\cdot d^3\cdot d_{cp}}{\Delta P_c\cdot d_\kappa^3}}\ м^3. \qquad (5)$$

where ΔP_c is resistance of valve (in mm H_2O).

In this form the formula is accurate for any valve. This may be due to the fact that for the same value of ventilation any valve rises to the same height as a gravitational valve having the same resistance and the same area of cross section. This occurs because for the same resistance the exhaust velocity of gas in slot is identical for various valves. Formula (5) in general form reveals the interconnection between slippage and resistance of automatic valve.

Dependence of resistance on ventilation, determined experimentally, is substituted in formula (5). Obviously, for the gravitational valve this is a constant, but for spring-loaded and other valves it is a variable.

Obtaining of experimental dependence of resistance of valve on ventilation is not a complicated problem and can be carried out everywhere. It is necessary to consider that by resistance of valve in formula (5) is implied maximum resistance for the whole respiratory cycle. For calculation of true slippage one should use formula:

$$\Delta V_1 = 0{,}157 \cdot q \cdot \sqrt{\frac{C_{x\rho} \cdot d^3 \cdot d_{c\rho}}{\Delta P_c \cdot d_\kappa^3}}\ м^3, \qquad (6)$$

where ΔP_c is resistance at the moment of change of phases of respiratory cycle (in mm H_2O).

In Fig. 3a, b, c is depicted dependence of slippage on ventilation for certain spring-loaded valves. Solid line depicts calculated-experimental dependence, plotted from measured resistances of valves. Consideration of graphs permits us to make two conclusions.

First, experimental points lie nearer to calculated curve than for gravitational valves; consequently, stability of work of spring-loaded valves is higher than for gravitational valves.

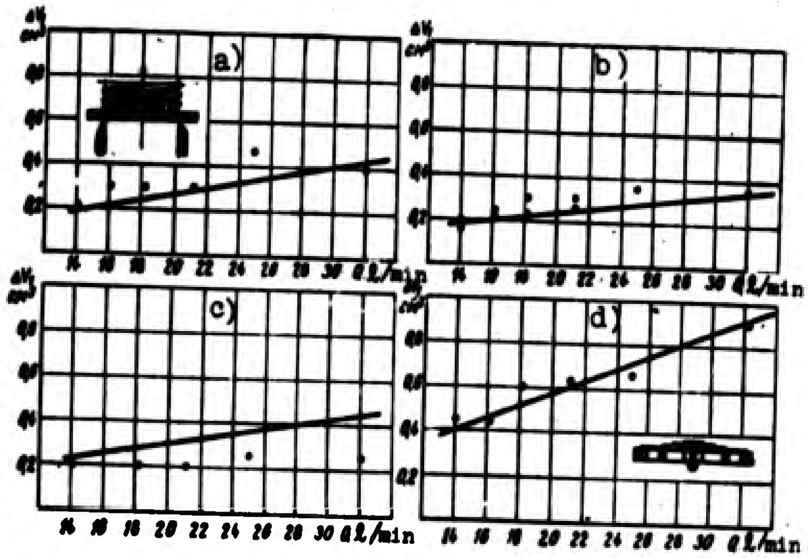

Fig. 3. Dependence of slippage on ventilation for automatic valves of different types. a) valve with spring No. 1 (weight 0.93 g); b) valve with spring No. 2; c) valve with spring No. 3; d) rubber antigas valve.

Second, absolute value of slippage for different spring-loaded valves are closed, in spite of considerable difference in spring force.

We apply calculation-experimental method of determination of slippage to any valve, including the rubber type with central fastening of plate. One of such valves (antigas) was investigated on experimental installation. Usually in such valves are established force, and consequently resistance, are in complicated dependence on height of rise of edges of plate.

Investigation of valve showed that its form is selected in such a way that resistance to breathing, as for the gravitational valve, does not depend on ventilation (within limits of up to 30 ℓ/min) and is equal to 6.6 mm H_2O. Consequently, according to formula (5), this valve with respect to slippage is also equivalent to the gravitational valve weighing 4.6 g and having the same area and the same resistance. Figure 3d illustrates this conclusion. On graph depicting dependence of slippage of rubber antigas valve on ventilation experimental points are located near calculated line plotted for gravitational valve with equal resistance.

Thus, it maybe asserted that slippage of an automatic valve of any form yields to approximate calculation if geometric parameters of valve and its resistance under investigated operating conditions are known.

Now it is possible to establish order of determination of bypass. On a leakage installation (see Fig. 1) there is determined dependence of rate of leakage on pressure drop in valve, where for approximation of true work of valve this dependence is determined for several positions of valve and average is taken as calculated. Then we establish law of change of pressure drop in valve in an actually working instrument. Mean value of pressure drop during the time of nonworking phase is determined. Average speed of leakage is determined. Time of nonworking phase is calculated. Product of this magnitude and average speed of leakage gives magnitude of leakage.

By well-known methods [5] there is determined dependence of resistance of valve on ventilation of the lungs. This dependence is put into formula (6), by which is calculated magnitude of slippage. For gravitational valves with known weight formulas (3) and (4) are more convenient to use.

Resistance of Valves (in mm H_2O)

Form of valve	Ventilation (in ℓ/min)					
	14,1	16,2	18,3	21,2	25	32,2
Gravitational with spring No. 1	21	21	21	21	21	22,4
Gravitational with spring No. 2	23,7	23,7	24,2	25	31,2	31,8
Gravitational with spring No. 3	13,2	15,8	15,8	17,[illegible]	17,1	18,5
Valve cage	5,3	6,6	7,9	9,[illegible]	10,5	14,5

Absolute values of bypasses, obtained on universal installation during tests of different valves and given in table, are of practical interest. As can be seen from data of table, under any conditions of breathing there is practically no danger of hypercapnia in narcosis apparatuses due to insignificance of bypasses of valves. This result was ensured by careful manufacture of investigated valves.

For artificial breathing apparatuses, for which questions of resistance of valve are not practically important, it is possible to recommend the antigas valve. These valves are especially at raised pressures in nonworking phase. They do not require lapping, since they are a serially mastered article.

Literature

1. Dollezhal' N. A. Khim. mashinostroyeniye (Chem. machine building), 1939, No. 7, str. 1.

2. Dollezhal' N. A. Obshcheye mashinostroyeniye (General machine building), 1941, No. 9, str. 2.

3. Nemerovskiy, L. I. Novosti med. tekhniki (News of medical technology), 1962, No. 6, str. 28.

4. Nemerovskiy, L. I. Trudy Vsesoyuzn. nauchno-issled. in-ta med. instrumentov i oborudovaniya (Transactions of All-Union scientific research institute of medical instruments and equipment). M., 1963, v. 1, str. 144.

5. Perel'mutr A. S., Kolokolova, T. D. Novosti med. tekhniki (News of medical technology), 1960, No. 5, str. 3.

6. Spravochnik mashinostroitelya (Machine builder's handbook). M., 1951, t. 1, str. 749.

7. Fialkov, A. N. Trudy Vologodsk. molochnogo in-ta (Transactions of Vologods. dairy inst), 1955, v. 13, str. 293.

8. Frenkel', M. I. In book: Konstruirovaniye i issledovaniye kompressorov (Designing and investigation of compressors). M., 1954, str. 36.

9. Shurgal'skiy, E. F. Prioborostreniye (Instrument Manufacture), 1958, No. 10, str. 7.

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