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# AERODYNAMIC EXCITATION OF SAME-TYPE NARROW-BAND PULSATIONS IN VARIOUS TECHNICAL DEVICES

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*Model experiments reproduce the character of flow pulsation processes developing in starting sections of gas compressor stations with an open return valve. Based on the analysis and comparisons it is assumed that, in the flow section of the valve, large-scale vortex structures are formed, and coupled narrow-band hydrodynamic and acoustic oscillations, similar to those observed in close-jet wind tunnels having an open working section and with a wing profile in flow, are generated. The generality of the excitation mechanism for intense disturbances in a gas flow with various heterogeneities is substantiated by the closeness of the relations for the dimensionless parameters, characterizing it to a common dependence.*

1. The purpose of the present investigation was sufficiently pragmatic: to find the cause of intense narrow-band pressure pulsations developing in the starting sections of main gas-compressor stations with an open return valve (Fig. 1) and to establish ways to prevent or attentuate them. The danger of these resonance oscillations stems, particularly, from the propagation of their acoustic mode to a considerable distance from the hydrodynamic source of disturbances.

This problem was solved in two ways: by reproducing the above-stated processes in model experiments and comparing them with those evidently similar in their nature but obtained in flows with other heterogeneities. Such an approach becomes necessary because it is impossible to experimentally obtain the viscosity and the Reynolds number of a full-scale flow, as is often the case in hydrodynamics.

The latter should not be regarded as an aggravating circumstance, since a preliminary analysis indicated the preservation of the basic mechanism of the considered narrow-band oscillations in a wide range of Reynolds numbers. A similar situation is observed, for example, in wind tunnels with an open working section differing markedly in dimensions, in which the same mechanism of the excitation of self-oscillations is realized at different flow velocity [1].

2. Since the objective of the experiments was to reproduce basic mechanism of resonance-type pulsation processes, it was assumed to be possible to carry out the investigation on a model of a short segment of a starting section of a compressor station with a total length of 1045 mm with a model of a return valve in the central part (Fig. 1). The tube length to the valve model was 295 mm and after it, 400 mm; the inside diameter of the tubes was 150 mm at the inlet to the model and 156 mm at the outlet. The diameter $d$ of the flow section of the valve seat was 135 mm. Minimal flow disturbances at the model inlet were ensured by a collector inside the damping chamber of the stand with a high-delivery pump, which permitted investigations at the mean flow velocity $V \sim 31-96$ m/sec in a flow section of the seat of the gate valve.

The air flow rate in the tubing was determined by measuring the velocity profiles at the tubing outlet with a Pilot tube. The pressure $p$ pulsations and their frequency spectra were measured using a 00026 precision noise gauge, an MK102/MV102 condenser microphone, a 02013 RFT recorder, a 01025 Robotron narrow-band analyzer, and a S1-107 multimeter.

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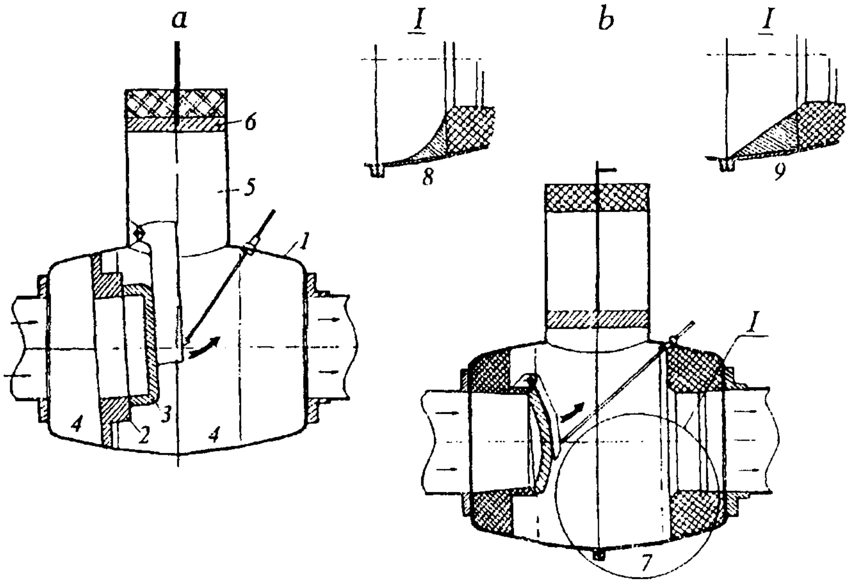


Fig. 1. Diagram of initial return valve (a) (1) valve frame; 2) seat; 3) shut-off disk; 4) cavities ahead of and beyond seat; 5) assembly hatch; 6) moving insert and model of return valve with convergent inlet (b) (7) variant 1 of flow section beyond seat; 8) variant 2; 9) variant 3).

The pulsations were analyzed in the frequency range $f = 20$ Hz – 20 kHz, which accounted for a significant part of the pulsation processes. In experiments, a microphone was installed practically flush with the tube wall at a distance of 100 mm upstream from the valve inlet and beyond the flow at the tube outlet.

Based on the measuring results we determined the dynamic pressure $q = \rho V^2/2$, the dimensional and dimensionless frequencies $f_a$ and $f_1 = f_a \nu / V^2$ of the narrow-band components of the pressure pulsation spectra $L(f)$, their mean square level $\sqrt{\langle p^2 \rangle}$, the intensity $\varepsilon_p = \sqrt{\langle p^2 \rangle}/q$, and the Strouhal numbers of intense disturbances $\mathrm{Sh} = f_a d/V$. Here $\nu$ is the kinematic viscosity of air and $\rho$ is its density.

The model Reynolds numbers $\mathrm{Re} = Vd/\nu$, which reached $8.9 \cdot 10^5$ in experiments, were smaller than full-scale ones, which did not impede the reproduction of the basic mechanism of the pulsation processes and the establishment of methods for their correction.

3. The study examined several variants of the flow section of the return valve to ascertain the effect of its individual geometric features on the excitation of resonance pressure oscillations in a flow. In the initial variant, they could be caused by vecesses ahead of the flow inlet to the seat and after it, and by a misaligned shut-off disk (Fig. 1a).

Via appropriate test changes of the flow section it was found that the source of narrow-band coupled hydrodynamic and acoustic pulsations was the cavity between the seat and the valve outlet. The gate valve and cavity ahead of the seat influence the flow structure, but it is determined by exactly the above-mentioned cavity. It should be noted that a cavity ahead of a seat is not an obligatory structural element of a return valve. It was also established that the volume of the assembly hatch, which was varied in experiments by moving an insert, has practically no effect on the generation of tone noise in a flow.

Major research, therefore, was carried out using a return valve in which the flow section between its inlet and seat was shaped as a convergent channel with slight contraction and the cavity after it in the first case was deformed somewhat and taken to be close to a cylinder (variant 1), in the second case it approached a part of a sphere (variant 2), and in the third case it was in the shape of a truncated cone (Fig. 1b). The shut-off disk in these experiments was maximally misaligned with the seat. The volume of the assembly hatch did not vary.

Typical frequency spectra of pressure pulsations determined at a distance of 100 mm upstream from the valve are presented in Fig. 2 for the three indicated variants of geometry of its flow section. It should be noted that, for the regimes with an intense narrow-band component of the spectra of pressure pulsations clearly noticeable

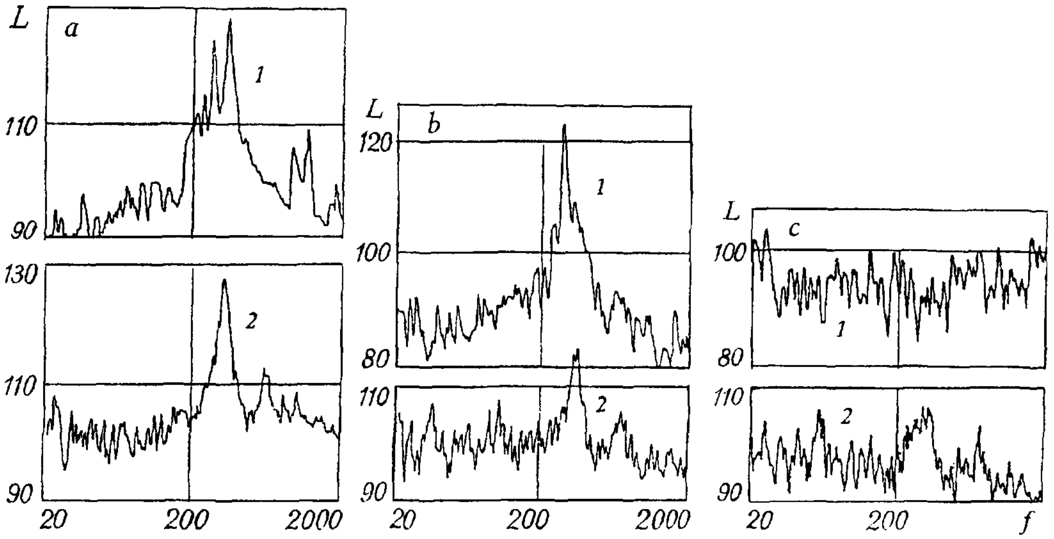


Fig. 2. Variants 1 (a), 2 (b) and 3 (c) in flow section of valve : a: 1) $V = 54.9$ m/sec; $\mathrm{Re} = 5.01 \cdot 10^5$; $\mathrm{Sh} = 0.85$; $\varepsilon_p = 2.76\%$; 2) 90.3; $8.24 \cdot 10^5$; 0.48 and 1.02; b: 1) $V = 55.5$ m/sec; $\mathrm{Re} = 5.16 \cdot 10^5$; $\mathrm{Sh} = 0.71$; $\varepsilon_p = 0.48\%$; 2) 89.9; $8.36 \cdot 10^5$; 0.52 and 0.27; c: 1) $V = 55.5$ m/sec; $\mathrm{Re} = 5.12 \cdot 10^5$; 2) 93.5 and $8.62 \cdot 10^5$. $L$, dB; $f$, Hz.

against a general background, practically harmonic oscillations of constant amplitude were observed on an oscillograph screen.

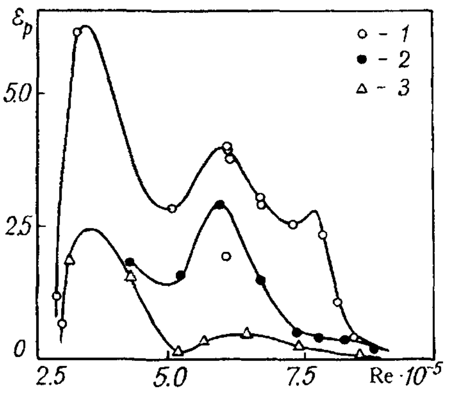
These regimes were the most characteristic for a valve with a well-developed and nearly cylindrical cavity downstream from the seat (Fig. 2a, 2). In the range examined, for smaller Reynolds numbers at mean frequencies of the order of 300–400 Hz, the intensity of narrow-band spectral components $\varepsilon_p$ at the site of measurements on the wall exceeded 6% (Fig. 3). Here, the Strouhal numbers were close to 1. Beyond the flow at the tube outlet, the spectra of pressure pulsations had the same form as during measurements on the wall upstream from the valve. A high-level tone noise associated with hydrodynamic disturbances in the valve are propagated upstream and downstream from it and over the entire spacious test stand.

As the Reynolds number increased, the spectra of pressure pulsations in the flow underwent nonmonotonic changes. The uncontrolled intermittence of flow regimes with various frequencies, carrying the main energy of pulsations (Fig. 2a, 1) or the presence of a stable ensemble of several energy-carrying frequencies becomes representative for the numbers $\mathrm{Re} > 5 \cdot 10^5$. Here, the intensity of narrow-band pressure oscillations $\varepsilon_p$ becomes lower than for $\mathrm{Re} < 5 \cdot 10^5$. Regime intermittence similar to that mentioned above was also observed at full-scale gas-compressor stations.

A salient feature of these regimes lies, therefore, in that to one Reynolds number there correspond several Strouhal numbers and several values of $f_1$, which are calculated on the basis of the energy-carrying frequency (Fig. 4). Consequently, the flow in the Sh–Re or $f_1$–Re plane of parameters is characterized by instability regions similar to those examined, for example, in [2]. Judging by the above-mentioned results of full-scale studies, such instability regions also exist for Reynolds numbers that are greatly in excess of those obtained experimentally.

In variant 2, the cavity between the seat and the outlet from a valve model, which is similar to a part of a sphere, is smaller in its dimensions that the one examined. Although the character of the frequency spectra of pressure pulsations in the flow remains about the same as in the first variant of the flow section, the intensity of narrow-band spectral components $\varepsilon_p$ decreases noticeably (see Fig. 3).

This trend is retained for a subsequent decrease in the cavity dimensions in the third variant, where the flow section after the seat has the form of a truncated cone. In this case, regimes were realized in which narrow-band components either did not stand out against the general background of the wide-band spectrum or their level did not differ much from it (see Fig. 2c).



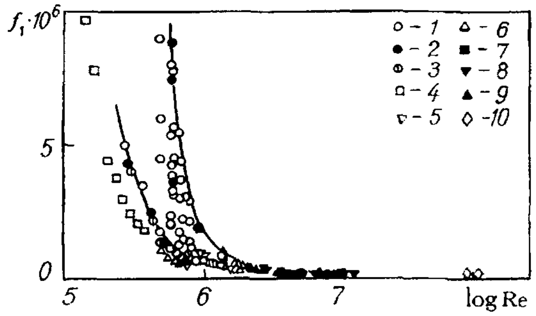


Fig. 3. Intensity of pressure pulsations as a function of the Reynolds number: 1, 2, and 3) variants of the flow section.

Fig. 4. Dimensionless frequency of a maximum discrete component as a function of the Reynolds number: 1, 2, and 3) variants of flow section of model of return valve; 4) T-4 wind tunnel with nozzle diameter $d_n = 0.6$ m; 5) T-20 wind tunnel with elliptic nozzle with axes $a = 0.706$ m, $b = 1.212$ m; 6) T-23 wind tunnel, $d_n = 0.5$ m; 7) T-102 tunnel, $a = 2.33$ m, $b = 4.0$ m; 8) T-103 tunnel; $a = 4.0$ m, $b = 2.35$ m; 9) T-5 tunnel, $d_n = 2.25$ m; 10) full-scale return valve of main gas-compressor station.

Analyzing experimental data, it should be borne in mind that the flow in a valve between the seat and the valve outlet is, in essence, a jet flow and, which is to a certain extent similar to the one observed in open working sections of closed-jet wind tunnels. Specifically, for the cases compared, the relative length for which the flow can be regarded as a jet flow is approximately the same. In fact, these are extreme representatives of the same class of flows.

Evidently, in the valve in shear flow downstream from the seat, large-scale vortex structures are formed, which can only generate, as in wind tunnels, intense narrow-band pressure oscillations. It was assumed hypothetically [1] that the acoustic emission is a consequence of the interaction of vortices with the edges of the diffusers of wind tunnels. A similar mechanism could be assumed to exist in a return valve. However, variations in the shape and rigidity of the diffuser edges and valve outlet have practically no effect on the self-oscillation parameters.

The conclusion suggests itself that an intense narrow-band noise is generated at a certain stage of the development of vortex structures with a critical longitudinal gradient, for example, of such a parameter as the amplitude of the oscillations developing in the vortex due to secondary instability and destroying it eventually. This occurs before the vortices contact the diffuser or the surface of the valve flow section whose geometry determines the vortex development. This is the only way that an acoustic emission could develop in the case of an isolated wing profile in a flow in study [3].

The acoustic emission directed upstream or, in wind tunnels, along a closed waveguide conduit realizes feedback in the cases considered. The feedback enhances hydrodynamic oscillations in an unsteady shear flow upstream from the site of generation of acoustic disturbances, which eventually forms a self-oscillation system with characteristic intense narrow-band resonance-type pulsations.

A change in the cavity shape in the return valve evidently affects the above-mentioned longitudinal gradient, acoustic emission, and, as a consequence, narrow-band pulsations in a flow. Proceeding with comparisons, it can be assumed that the considered alteration of the cavity geometry in the return valve is to a certain extent equivalent to the gradual transition from an open to a closed working section in a wind tunnel. In a closed working section, narrow-band oscillations do not develop with a relatively small flow reduction inside the nozzle.

In the above analysis it was assumed that the mechanisms of excitation of self-oscillations in flows with noticeably different heterogeneities were of the same type. Such an approach was assumed to be justified by a common original cause for the development of narrow-band pulsations: instability of the shear flow on the jet periphery or in the wake, and by the same outcome of secondary instability: acoustic emission on the breakdown of vortex structures.

Therefore, the functions $f_1$(Re) or Sh(Re), characterizing self-oscillation processes in return valves and wind tunnels, can be expected to be close. Figure 4 presents the correlations of $f_1$(Re) for three variants of a return valve and for six wind tunnels. In the latter case, use was made of experimental data [1] for wind tunnels with a nozzle diameter of 0.5 m through 2.25 m, and also with nozzles of elliptic cross section and major axes at the outlet equal to 4.0 × 2.35 m and 2.33 × 4.0 m. In these two cases, the Reynolds numbers were calculated on the basis of the hydraulic diameter. Also plotted are the data of full-scale experiments in which the kinematic viscosity of the gas differs from $\nu$ for air by two orders of magnitude. As is seen, the functions compared really turned out to be close.

**Conclusions.** However paradoxical it may seem at first glance, coupled resonance-type hydrodynamic and acoustic oscillations are generated in flows with noticeably different heterogeneities in much the same fashion. The generation of pulsations of a dangerous level in a flow can be avoided by slight alterations in the flow section of return valves of the starting sections of main gas-compressor stations.

## NOTATION

$V$, mean flow velocity in flow section of seat of gate valve; $d$, diameter of flow section of seat; $L$, level of pressure pulsations; $f$, pulsation frequency; $d_n$, diameter of wind tunnel nozzle; $a$ and $b$, axes of elliptic cross section of nozzle of wind tunnel; Re, Reynolds number; Sh, Strouhal number. Subscripts: a, self-oscillations; 1, dimensionless quantity; $p$, pressure.

## REFERENCES

1. S. P. Strelkov, G. A. Bendrikov, and N. A. Smirnov, *Pulsations in Wind Tunnels and Methods of Damping Them*, Tr. TsAGI, No. 593 (1946).
2. G. Schlichting, *Turbulence* [Russian translation], Moscow (1962).
3. A. G. Munin, A. G. Prozorov, and A. V. Toropov, *Uch. Zap. TsAGI*, **21**, No. 3, 28-38 (1990).