Studies by PIV-methods of self oscillating hydrodynamic processes in the elements of pipeline

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Abstract. Investigation of the self-oscillation regimes in the flow chamber modelling elements of stop valves in the pipeline in the systems of heat exchange in the power plants were performed by using PIV methods. Dependency of parameters of self-oscillation regimes on the parameter of the gap between the inlet and outlet pipe line in the chamber was investigated. Simultaneous measurements of the hydrodynamic and acoustic fluctuations allows us to offer explanation of the observed regimes.

1. Introduction

Self-oscillation regimes are quite common in hydrodynamic processes. Their occurrence in various technical systems can lead to negative effects due to non-permanent (cyclic) and non-uniform (complicated spatial distribution) influence on structural elements, complicates diagnostics and control of flow patterns, etc. Also, these modes can be a source of narrow-band acoustic noise, which can also be a negative factor. In [1], a number of problems are discussed, which describe typical system configurations in which such regimes arise, and also illustrates the use of the Particle Image Velocimetry (PIV) method for obtaining the flow velocity field in them. At the same time, considerable attention is paid to the study of flows in a turbulent boundary layer, on a solid surface in the presence of various types of cavities and protrusions (see [2]). Such configurations can be very relevant from the point of view of applications associated with flows in pipelines of different configuration. Flow-through elements such as splitters (twins, tees, etc.), pipe joints of various transverse sizes and cross-section types, bends can be sources of self-oscillatory modes. These elements are typical for heat exchange systems in power plants including nuclear ones.

This work is devoted to the study of self-oscillation regimes in the simulation of hydrodynamics of flows in the pipeline elements of power plants. In particular, the case of the flow part (parallelepiped), the inlet and outlet pipes to which had a diameter of smaller transverse size of the flow-through area, was considered. This configuration simulated the area in which the valves of the pipeline system could be located. The dependence of the characteristics of the self-oscillatory flow regime on the gap between the pipes inside the flow area was investigated. An explanation of the physics of the observed process was proposed.
2. Experiment and measurements
2.1. Experimental setup
Experiments were carried out on a setup consisting of a model of the flow part, supply and discharge pipes, an exhaust fan, a absorption device to prevent pulsations caused by the fan operation (see figure 1).

![Aeroacoustic setup](image)

Figure 1. Aeroacoustic setup (1 – inlet pipe, 2 – model of the flow part with installed vibrator microphone, 3 – measuring table, 4 – outlet pipe, 5 – device for absorbing pressure pulsations, 6 – fan).

To exclude the influence of disturbances from the fan on the measurement processes in some experiments it was installed in an anechoic chamber and a device is installed in front of it to absorb pressure pulsations propagating along the air flow in the pipes.

The model of the flow part (chamber) was a parallelepiped 60×80 mm, and 140 mm high (all dimensions are internal) of plexiglas 8 mm fixed on the table. The table is mounted on special vibration dampers that prevent the transmission of parasitic vibrations. Air was supplied to the models and removed with the help of sets of polypropylene pipes 1.5 mm thick, of various length, but of the same outer diameter – 50 millimeters. The pipes were attached to the optical table, forming a single system together with the model flow part (figure 1). A conical nozzle was attached to the system inlet to reduce airflow resistance.

All measurements were performed for the constant fan speed. A smoke spray generator seeding an aerosol with average droplet size of 5 microns was used for PIV-measurements. The generator was located in front of the entrance nozzle at a distance of about 1 m and operated in a pulsed mode, synchronously with the survey. The duration of smoke seeding was about one second.

2.2 Image processing
It should be noted that in the process of carrying out PIV-experiments the seeding density varies significantly with time due to the irregular character of the smoke generator operation. Therefore, a dynamic background calculation was used: each pixel of the image synthesized for each frame is the 20th percentile for a set of pixels located in the same place in a sample of the 100 frames closest to a given moment. The background image was subtracted from the frame to reduce static noise and parasitic flare. After subtracting the background, a cross-correlated image processing in accordance to PIV-method. The velocity field was calculated based on the cross-correlation processing of successive frames on the rectangular grid. An adaptive two-pass scheme was used. At the first stage, the displacement field was roughly calculated with a comparison window of 128×128 px (overlapping
50%). The resulting field was filtered and interpolated to the grid in increments of 2 times less. On this grid, with a preliminary symmetric shift of the interrogation windows, the main calculation of the displacement were carried out: the window size was 64×64 px (overlap 50%). To clarify the fractional part of the bias we used the Gaussian approximation of the peak of the cross-correlation function at the three nearest points.

![Images](a) (b) (c) (d)

**Figure 2.** (a) – view from above on the model of flow part and laser (on the top of the frame), (b) – side view on eyi high speed camera NAC-HX3, (c) – 3D scheme of experiment, (d) – gap between the pipes in the flow part.

The main filtering of obtained velocity values was carried out in time sequence for each point of the spatial grid. The values for which at least one of the found components by more than three standard deviations differs from the average value over the entire record (for a given point) were filtered out through two passes. As a result an average of 5% of the points were discarded.

Sound pressure levels were monitored using a microphone which could be placed in various places, both outside the layout and inside it, depending on the measurement mode, in addition to the main measurements using the PIV-method. The frequency of sound pressure was determined in the range of 50÷8000 Hz.

Initially the pipes were installed flush with the walls without protruding edges \((L = 60 \text{ mm})\). In this configuration a sound was clearly heard which as shown by measurements from a microphone, had a frequency of 340 Hz. Also measurements recorded a weak noise at the second harmonic of 680 Hz. Then they began to push the inlet pipe into the flow area. Changing the size of \(L\) to 48 mm led to instability of the sound, a sharp decrease in the amplitude of the sound to the level of external interference. The absence of discrete noise was maintained in the interval \(L\) up to 38 mm. An even greater reduction in the gap between the pipes led to the resumption of the tonal sound of the system at a higher frequency of 680 Hz which was maintained up to a distance of 30 mm.

For performing PIV-measurements three different cases of gaps between the pipes: 55 mm, 42 mm, 35 mm were chosen, corresponding observed picture of acoustic noise. Figure 3 presents a comparison of averages, and figure 4 shows instantaneous velocity fields. The mean velocity fields practically do not differ, but the instantaneous ones demonstrate the presence of large-scale structures at the boundary of the jet in cases when acoustic noise is observed. Even more eloquent confirmation of the occurrence of the self-oscillatory regime in the flow is a comparison of the spectra of flow fluctuations shown in figure 5. At each point in the coordinate grid of the velocity field, there were spectra that were then averaged over the entire field. The fluctuation spectra of the vertical and horizontal velocity components confirm the presence of hydrodynamic perturbations of the corresponding frequencies.

### 3. Interpretation of the mechanism of self-oscillating regime

In order to find out how the distance \(L\) influence on the occurrence of the self-oscillation mode and the noise emission the results of preliminary numerical simulation of the flow in the model flow section were considered. Figure 6 shows one of the frames of the instantaneous implementation of the system of vortices formed in the flow part area.
Figure 3. Mean velocity field (a) gap 35 mm, (b) 42 mm, (c) 55 mm.

Figure 4. Instantaneous velocity field (a) gap 35 mm, (b) 42 mm, (c) 55 mm.

Figure 5. Spectrum of velocity pulsations. Left column corresponding horizontal component of velocity, right – vertical component of velocity. Top raw corresponding gap 35 mm, mean 42 mm, low 55 mm.
As can be seen from figure 6 a vortex sheet (thin surface with nonzero vorticity) forms at the boundaries of the air jet penetrating from one pipe to another which separates the main flow air from the air in the stagnant zone of the chamber cavity. This vortex sheet represents a jump in the longitudinal component of velocity from the value in the main part of the flow to values close to zero in the stagnant zone of the chamber and extends the value of $L$ from the edge of the incoming pipe to the edge of the outlet pipe.

**Figure 6.** Vorticity distribution obtained by numerical simulations.

**Figure 7.** Evolution of the vortex flow in the chamber. Frames are obtained by a large exposure of 10 ms.

As is well known from hydrodynamics the vortex sheet is an unstable structure which with the slightest inhomogeneities tends to “collapse” into a set of large discrete vortices. The process of the occurrence of such a vortex can also be observed in figure 6.

This process is well confirmed by sequence of images obtained with a long (compared to PIV-measurements) exposure. Figure 6 shows the storyboard of a periodic process of the evolution of a vortex sheet in the gap between the pipes in the generation mode of the most intense vortices at a frequency of 340 Hz. This periodic process can be represented as four stages: the first stage is an increase in the intensity of vorticity near the edge of the inlet pipe (figure 7 (a)); the second stage is the loss of stability of the vortex sheet and its folding into a discrete ring vortex (figure 7 (b), right, above); the third stage – the movement of the vortex downstream (figure 7 (c), left, bottom); and the final fourth stage is the blow of the vortex against the edge of the outlet pipe and its resorption on its walls (figure 7 (d), right, bottom).

The most important thing in this process is that the indicated periodical motion of the vortices leads to a periodical change in the flow rate of air flowing through the inlet and outlet sections of the chamber. This vortex can be identified with a fictitious dipole source, oriented longitudinally, exciting acoustic waves.

The phenomenon described above explicitly reveals the reason for the influence of the distance $L$ on the noise emission process, since $L$ and the flow rate $U$ explicitly determine the time during which a vortex forms and reaches the edge of the outlet pipe and hence the frequency of hydrodynamic instability. Obviously this frequency of hydrodynamic instability in some cases is synchronized with
other resonances of the system which generates self-oscillations and the accompanying acoustic radiation.

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