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EFFECT OF FLUID VISCOSITY ON NOISE OF BILEAFLET PROSTHETIC HEART VALVE[**]

Background. Numerical simulation and experimental research have been used as powerful tools to understand and predict the behavior and mechanics of the operation of natural heart valves and their prostheses in natural and pathological conditions. Such studies help to evaluate the effectiveness of the valves, their design and the results of surgical procedures, to diagnose healthy and impaired function of the heart valves. There is an actual problem in creating more reliable methods and tools for the operation diagnostics of mechanical heart valves.

Objective. The aim of the research is to investigate the effect of fluid viscosity on the hydroacoustic characteristics of jets that flow from a semi-closed and open mechanical bileaflet heart valve. To study the possibility of using hydroacoustic measuring instruments as diagnostic equipment for determining the working conditions of the bileaflet prosthetic heart valve.

Methods. The experimental research was carried out by means of hydroacoustic measurements of the hydrodynamic noise in the near wake of the side and central jets of the glycerin solution and the pure water flow downstream of the prosthetic bileaflet heart valve.

Results. The effect of fluid viscosity on the hydroacoustic characteristics of the jets that flow from a semi-closed and open mechanical bileaflet heart valve has been experimentally determined. Integral and spectral characteristics of the hydrodynamic noise of jets of the glycerin solution and the pure water flow downstream of the bileaflet mitral heart valve for different fluid rate were detected.

Conclusions. In the stream conditions of pure water, the integral characteristics of the pressure field are lower than in stream conditions of the aqueous glycerin solution. As the glycerin concentration in the solution increases, increase average pressures and especially RMS pressure fluctuations. The spectral levels of the hydrodynamic noise in the near wake of the side jet of the glycerin solution are lower than for water flow in the frequency ranges from 1 to 7-8 Hz and from 100 to 1000 Hz for fluid rate 5 l/min. For higher fluid rates, the spectral components of the hydrodynamic noise in the near wake of the side jet of the glycerin solution of the semi-closed mitral valve are higher than that for the pure water. The greatest difference (1.5–1.8 times) in the spectral levels is observed in the frequency range from 10 to 100 Hz for the fluid rate 15 l/min.

Keywords: prosthetic bileaflet heart valve; kinematic viscosity; hydroacoustic measurement; pressure fluctuations.

Introduction

In the human body, the heart with the vessels forms the cardiovascular system, which has two circles of circulation (large and small). The heart is divided by partitions into four chambers: two ventricles and two atria (left and right). Between them there are four valves: mitral, tricuspid, aortic and pulmonary. Valves open and close at the right time, forming a unidirectional blood movement and interfering with regurgitation, that is, the reverse flow of blood. Natural heart valves consist of thin, flexible leaflets that are opened and closed, forming a pulsatile blood flow. When the leaflets of the heart valves are damaged, they are often replaced with prostheses. In the United States, over 80,000 heart valve transplant operations are performed annually and over 300,000 heart surgery operations worldwide [1, 2]. Many of the mechanisms that form the basis of the pathophysiology and progress of heart disease have not yet been fully explored, creating difficulties in the medical therapy development [3, 4]. In connection with this, the most effective treatment for the pathology of the affected valves is surgical intervention. Now there are three types of prostheses used for heart valve transplantation, namely, mechanical, bioprosthetic, and homotransplant valves. However, each prosthesis type has its advantages and disadvantages. Thus, the most commonly used mechanical valves are exposed to intensive blood thrombus formation and require lifelong consumption of anticoagulants that reduce (but do not exclude) the risk of valve embolism by blood thrombi. In general, mechanical valves are manufactured in the form of a bileaflet

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structure consisting of a ring attached to the heart tissues supporting two movable discs.

The main focus of biological and medical research is the search for methods and tools to reduce thrombus formation which often observed in the area of hinges supporting the leaflets or discs of mechanical valves, where unstable inhibited and recurrent streams are observed. Optimization of the valve is a rather complex task since high-velocity regions and correspondingly high shear stresses lead to platelet activation and erythrocyte destruction, and low-velocity regions cause increased formation of thrombi. Over the past two decades, numerical simulation and experimental research have been used as powerful tools to understand and predict the behavior and mechanics of the operation of natural heart valves and their prostheses in natural and pathological conditions. Such studies help to evaluate the effectiveness of the valves, their design and the results of surgical procedures, to diagnose healthy and impaired function of the heart valves.

Since the heart sounds are always audible and only the deviation of their characteristics from the norm indicates pathology, the appearance of intense noises of the cardiovascular system becomes a signal of normal blood flow disruptions. As studies [5, 6] show, mainly heart noises indicate damage to the operation of ventricular valves. The mitral valve insufficiency and stenosis of the aortic valve cause noise at the beginning of the systole, and diastolic noise indicates aortic valve insufficiency.

Clinical studies of blood flow in the atria and ventricles are limited to the spatial and temporal resolution of non-invasive instruments such as echo-Doppler cardiography and magnetic resonance imaging [7—9]. Currently, the most common method for diagnosing heart valves is the echo-Doppler cardiography. Often this method does not detect thrombus formation on the surface of mechanical valves. This is due to the fact that the echo-Doppler cardiography registers the pressure drop through the open valve. But this pressure drop was not obtained from direct measurements, but calculated from semiempirical relationships. Such calculations lead to rough estimates and give a large error in diagnostic studies. Especially a lot of errors arise, for example, in the operation diagnostics of mechanical mitral valves. This is due to the fact that the pressure drop during blood movement through the mitral valve prosthesis is much less than through the aortic valve prosthesis. Therefore, a high percentage of errors in the pressure drop evaluation by means of echo-Doppler cardiography occur with thrombosis of bileaflet mechanical mitral valves. In this regard, there is an actual problem in the creating of more reliable methods and tools for the operation diagnostics of mechanical heart valves.

Preliminary research with positive result for the use of hydroacoustic and vibroacoustic measurement techniques as possible portable equipment in addition to the existing echo-Doppler cardiography for the diagnostics of thrombosis of prosthetic mitral valves was proposed and conducted. Hydroacoustic or vibroacoustic measurements are relatively inexpensive non-invasive measurements that can be easily integrated into standard ultrasound measurements as an additional indicator of operability of prosthetic mitral valves. This is shown in the papers [10—12] that when modeling of the thrombus formation on one of the mechanical valve leaflets (semi-closed valve), the hydroacoustic parameters of the jets that flow out of the valve holes differ from those that occur in the conditions of the open valve leaflets. It should be noted that in these studies water was used as a working medium, and as known, the blood is a non-Newtonian fluid that has a kinematic viscosity greater than a kinematic viscosity of pure water. In this connection, the problem arises to determine the influence of the viscosity of the working medium on the possibility of hydroacoustic or vibroacoustic diagnostic of thrombus formation on the leaflets of mechanical bileaflet heart valve.

Problem statement

The aim of the research is to investigate the effect of fluid viscosity on the hydroacoustic characteristics of jets that flow from a semi-closed and open mechanical bileaflet heart valve. To study the possibility of using hydroacoustic measuring instruments as diagnostic equipment for determining the working conditions of a bileaflet prosthetic heart valve.

Experimental setup and research technique

Experimental research was carried out in the micro-biofluid-dynamic Laboratory (μBs) of Politecnico di Milano. Physical simulation of the flow through the heart valve was performed on a mechanical bileaflet heart valve (Fig. 1) of Sorin Biomedica Cardio (Italy). Transplantation of such a valve with a diameter $d = 25$ mm is performed mainly in the left ventricle of the heart with aortic or mitral valve prosthetics [13, 14]. In research, a mechanical bileaflet valve was placed in the mitral valve position between the left atrium and the left ventricular chamber. The model of the atrium and the left ventricle was made of organic glass and is shown in Fig. 2. Fluid goes through the inlet pipe entered inside the model of the atrium *1*. As a working fluid, water and an aqueous solution of glycerin of various concentrations were used. Inside the atrium model, there were nets and grids to destroy the large-scale turbulence of the input stream. From the atrium model, the working fluid entered inside the model of the left ventricle *2* through a mechanical bileaflet mitral valve. The fluid from the left ventricle model flowed either through the aortic valve *3* or through the outlet *4*. Inside the model of the left ventricle are coordinate devices *5* for attachment and movement of the sensors in the vertical plane.

Fig. 1. Mechanical bileaflet heart valve

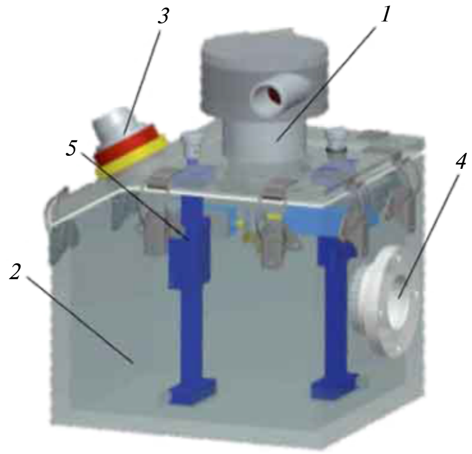


Fig. 2. Test bench: *1* – atrium; *2* – left ventricle; *3* – aortic valve; *4* – outlet; *5* – coordinate devices

The liquid flow through the open mitral valve is divided into three jets – the central and two side jets, which are schematically shown in Fig. 3. In the near wake of these jets, there are a block of pressure fluctuations and absolute pressure sensors, which are mounted on the coordinate device *5* (see, Fig. 2). The sensor block moves along the investigated jet and records the pressure field or hydrodynamic noise of the jet at a different distance from the valve. The mitral valve fixing device between the model of the atrium and the left ventricle made it possible to rotate the valve around its axis. This allowed investigating separately the hydrodynamic noise of the near wake of the central or lateral jet by pressure sensors.

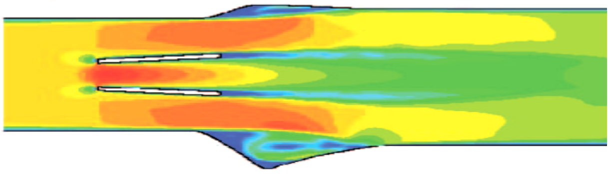
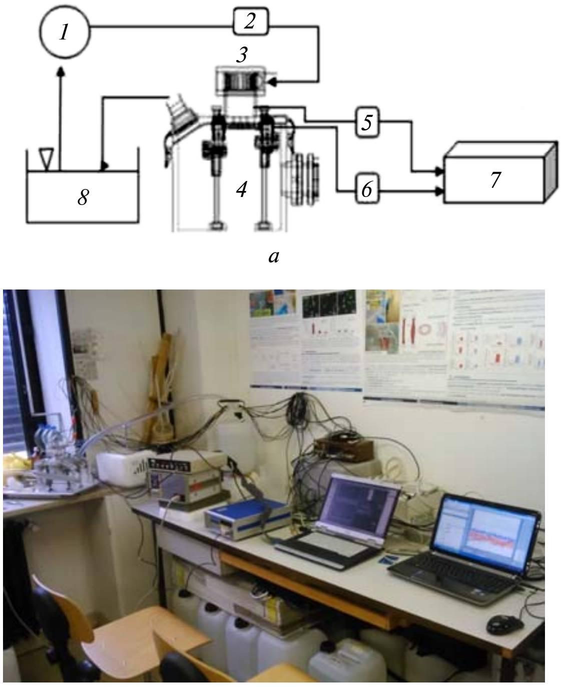


Fig. 3. Flow through the open mitral valve

In the research, a stationary flow of working fluid through the mechanical bileaflet heart valve was used. The pump supplies pure water or glycerin solution with a fixed rate through the mitral valve. The scheme and picture of the experimental setup are shown in Fig. 4. The pump *1* supplies the working fluid inside the atrial model *3* and through the mitral valve inside the model of the left ventricle *4*, and then in an open tank *8*. Monitoring of fluid flow rate and measurement of hydrodynamic noise and vibration is carried out by sensors *2*, *5*, and *6*, respectively. The registration, processing and analysis of research results are carried out on specialized measuring complexes and computers *7*.

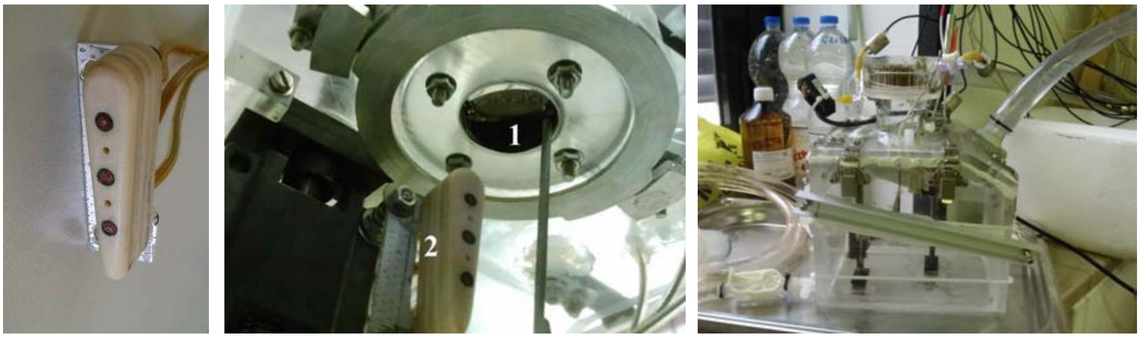


a

b

Fig. 4. Experimental setup: *a* – scheme, *b* – picture

A block of pressure sensors *2* and its location downstream of the mitral valve *1* are shown in



a *b* *c*

Fig. 5. Sensor position: *a* – pressure sensors, *b* – location, *c* – external sensors

Fig 5, *a*, *b*. In Fig. 5, *c* is a picture of atrial and left ventricular models with absolute and dynamic pressure sensors, accelerometers and acoustic heart sensors. Three miniature piezoceramic pressure fluctuation sensors (diameter of the sensitive surface d_s = 1.3 mm) [15, 16] and two piezoresistive differential absolute pressure sensors are installed [17] (Fig. 6). The sensors are placed in a line along the investigated jet at a distance of 5 mm (see, Fig. 5, *a*). The pressures inside the models of the atrium and left ventricle are recorded by piezoresistive absolute pressure sensors (three sensors). The vibrations of the atrium, sensor holder, and left ventricle model are measured by piezoceramic accelerometers (two accelerometers) [15, 18]. Sound field on the surface of the atrium model and of the left ventricle model is recorded with two acoustic heart sensors.

Fig. 6. Pressure and acceleration sensors

The electrical signals of the sensors, amplified and filtered by the appropriate equipment, come to a 16-channel 16-bit analog-digital converter connected to a computer. At the same time, the signals are recorded from twelve sensors that measure the fields of pressure, velocity, sound and vibration, both inside and outside the models of the left ventricle chamber and the atrium. This enabled to determine the space-time characteristics of the investigated fields, and also to investigate the transformation of the measured parameters upon transition from the internal volume of the atrium and left ventricular models to the external environment and to the outer surface of these models.

Processing and analysis of experimental results were carried out using apparatus and algorithms of mathematical statistics and probability theory. For this purpose, Brüel and Kjær specialized analyzers, and personal computers were used. After processing the experimental data, the integral characteristics of the investigated physical parameters (mathematical expectation, variance, mean-square values of random variables), spectral and correlation functions were obtained. Autospectra, cross spectra, coherence functions and spatiotemporal correlations allowed determining [19, 20] the relationship between the investigated fields, the direction and transfer velocity of hydro and vibro-acoustic parameters and identifying the investigated physical quantities' change sources, their location, scales in space and time.

The research program included the simultaneous measurements of static and fluctuating pressure near the central and side jet downstream of open and semi-closed mechanical bileaflet heart valve, inside the atrium and left ventricular chamber models, and vibration and sound on the outer surface of these models and velocity fluctuations at the entrance of the atrium. The location of the pressure sensor block downstream of the bileaflet mitral valve is shown in Fig. 7. In Fig. 7, *a* is shown the moment of measurement of the hydrodynamic noise of the central jet for the operating condition of the open valve. Fig. 7, *b* shows a semi-closed valve and the sensors, which are located in near wake of central jet. In Fig. 7, *c* is shown a picture of the open mitral valve and the sensor block located near the side jet and in Fig. 7, *d* – measurement of the noise of the near wake of the side jet and semi-closed valve. The distance between the pressure sensors (x), which are located in the sensor block, and the leaflets of the heart valve varied from 25 mm to 45 mm. The flow rate of the working fluid (Q) through the mitral valve was ranged from 5 to 15 l/min. As a working fluid, pure water and an aqueous glycerin solution of various concentrations from 35 to 43 % were used. The glycerin solution and water kinematic viscosity varied from 3.2 to 4.3.

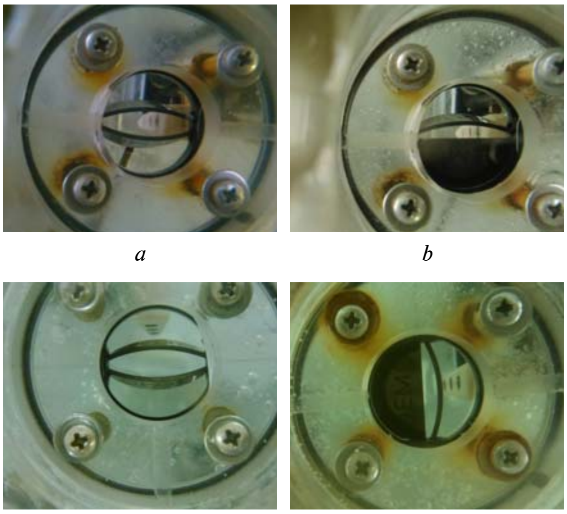


Fig. 7. The central jet noise measurement: open (*a*) and semi-closed valve (*b*) and side jet: open (*c*) and semi-closed valve (*d*)

Research results and discussion

According to the developed research program, integral (in the general frequency band) and spectral characteristics of fields of pressure, velocity and vibrations were determined. The spectral characteristics were calculated using fast Fourier transform of the fluctuations of investigated physical quantities using the Hanning weighting windows. Integral characteristics (mean and RMS values) allowed determining the energy of the investigated processes in the frequency band from 0.01 to 1000 Hz. Spectral characteristics represented the levels of physical quantities in narrow frequency bands.

In Fig. 8, *a* is shown the mean values of pressure, and in Fig. 8, *b* is presented the RMS values of pressure fluctuations near the side jet of the semi-closed mitral valve at a distance of 25 mm or $x = d$ from its base, depending on the flow rate for the stream of pure water and glycerin solutions of different concentrations. Curve *1* represents the pure water flow which has a kinematic viscosity $\nu = 1.01 \cdot 10^{-6}$ m^2/s, curve *2* — the glycerin solution flow with a kinematic viscosity of 3.2ν, curve *3* — the glycerin solution flow with a kinematic viscosity of 3.8ν, and curve *4* — the glycerin solution flow with a kinematic viscosity of 4.3ν. The integral characteristics of the pressure field of near wake of the jet downstream of the semi-closed, as well as open (not shown) mitral valve increase as the fluid rate increase. In-stream conditions of the pure water, the integral characteristics of the pressure field are lower than in stream conditions of the aqueous glycerin solution, average pressures and especially RMS pressure fluctuations increase as the solution glycerin concentration increase.

Comparison of mean values of pressure and RMS values of pressure fluctuations for the operating conditions of a semi-closed and open valve is shown in Fig. 9. The measurements were made in the near wake of the side jet and the glycerin solution flow with a kinematic viscosity of 4.3 greater than the kinematic viscosity of the pure water. Curve *1* represents a semi-closed valve, and curve *2* — an

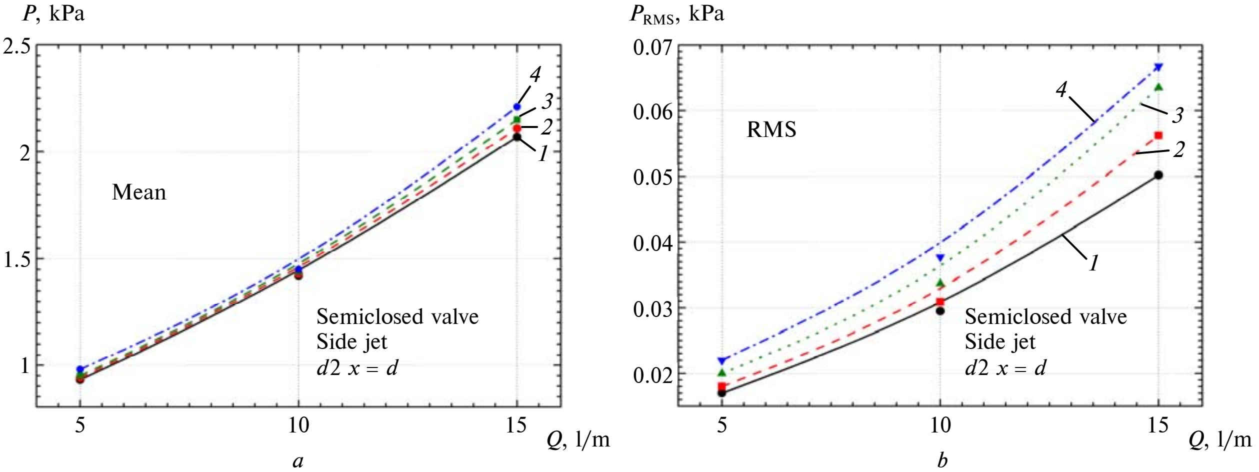


Fig. 8. Integral characteristics of pressure field: *a* — mean pressure; *b* — root-mean-square values of pressure fluctuations

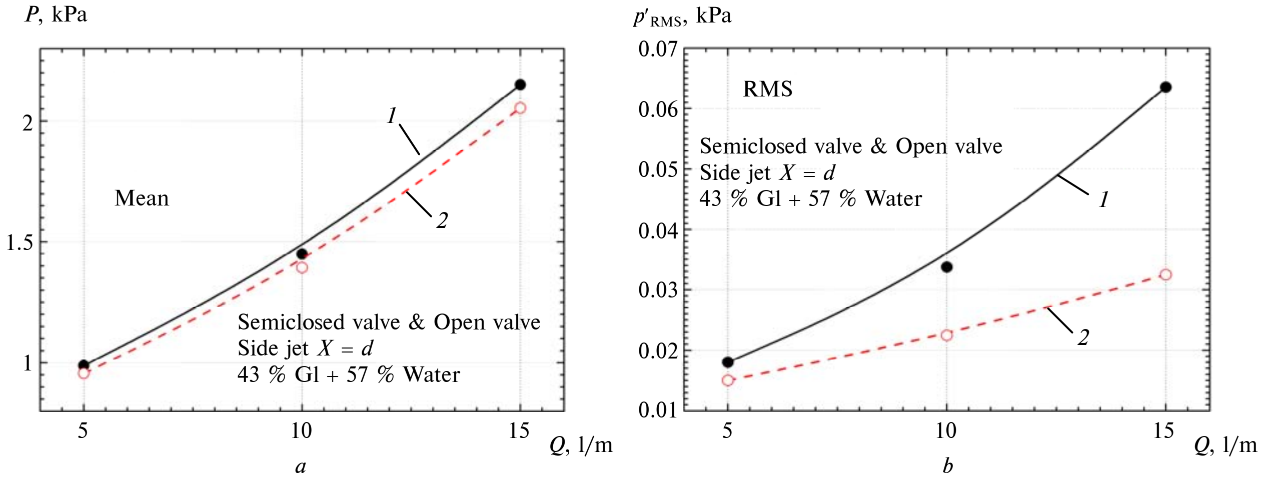


Fig. 9. Comparison: *a* — mean values of pressure, *b* — RMS values of pressure fluctuations

open valve. The mean values of pressure (Fig. 9, *a*) and RMS values of pressure fluctuations (Fig. 9, *b*) near the side jet of the semi-closed valve are higher than near the side jet of the open valve. The difference of the pressures increases as the glycerin solution flow rate increase. Thus, at the flow rate of 15 l/min, the mean pressure increases by almost 5 %, and the RMS values of pressure fluctuations are almost 2 times higher.

The spectral power densities of the pressure fluctuations in the near wake of the side jet of the open valve are shown in Fig. 10. The spectra were measured for the pure water flow and the glycerin solution with a kinematic viscosity of 4.3ν. The distance between the pressure fluctuation sensors and the valve leaflets changed as $x = d$ (curves *1* and *4*), $x = 1.1d$ (curves *2* and *5*) and $x = 1.2d$ (curves *3* and *6*). The first three curves were measured for the pure water flow, and the last three curves were measured for the glycerin solution flow. The spectral power densities of the pressure fluctuations were measured for a fluid rate $Q = 5$ l/min (Fig. 10, *a*), $Q = 10$ l/min (Fig. 10, *b*) and $Q = 15$ l/min (Fig. 10, *c*). The spectral levels of hydrodynamic noise increase both in the low-frequency region and in the high-frequency region as the fluid rate increase. This indicates that

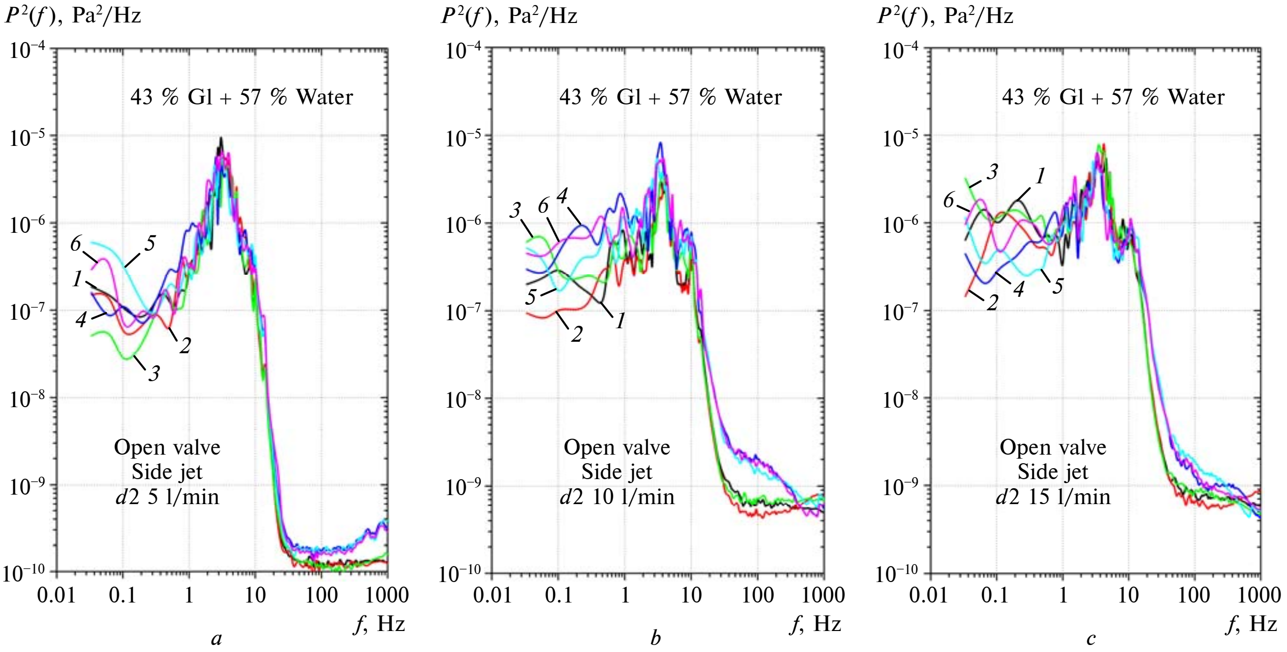


Fig. 10. Spectral power densities of the pressure fluctuations for open valve and fluid rate: *a* — $Q = 5$ l/min, *b* — $Q = 10$ l/min, *c* — $Q = 15$ l/min

the intensity of large-scale vortex structures (generating low-frequency pressure fluctuations) and small-scale eddies that are separated from the leaflets of the valve during fluid flow through the open valve are increased. The noise generated by small-scale vortices (the high-frequency part of the spectrum) in the glycerin solution is much higher (see, for example, Fig. 10, *b* or Fig. 10, *c*). For the low fluid rate, spectra of pressure fluctuations of the pure water flow through the open valve in low-frequency region are higher than for the glycerin solution flow. The maximum values of the pressure fluctuations were observed at a frequency f_{max} = 3.55 Hz for the pure water flow and f_{max} = 3.24 Hz for the glycerin solution flow and fluid rate Q = 5 l/min (Fig. 10, *a*). The maximum of the spectral levels of hydrodynamic noise was obtained for the pure water flow by a fluid rate Q = 10 l/min at a frequency f_{max} = 3.76 Hz and for the glycerin solution flow f_{max} = 3.39 Hz. For fluid rate Q = 15 l/min (Fig. 10, *c*) the maximum of the pressure fluctuations has occurred at a frequency f_{max} = 4.25 Hz (pure water) and f_{max} = 3.61 Hz (glycerin solution).

The spectral power densities of the pressure fluctuations in the near wake of the side jet of the semi-closed valve are shown in Fig. 11. Here the symbols of the curves are identical to Fig. 10. Unlike the open valve, the intensity of the hydrodynamic noise for the maximum investigated fluid rate through the semi-closed mitral valve is substantially higher than for lower fluid rates (see, for example, Fig. 11, *b* and Fig. 11, *c*). The values of the frequencies, where the maximum levels of pressure fluctuations are observed, have also changed. Thus, for a fluid rate Q = 5 l/min (Fig. 11, *a*), have the frequency f_{max} = 4.36 Hz (pure water) and f_{max} = 3.58 Hz (glycerin solution), for Q = 10 l/min (Fig. 11, *b*) – f_{max} = 4.50 Hz (pure water) and f_{max} = 3.80 Hz (glycerin solution) and for Q = 15 l/min (Fig. 11, *c*) – f_{max} = 4.85 Hz (pure water) and f_{max} = 4.12 Hz (glycerin solution). Consequently, the frequency of maximum levels of pressure fluctuations increases as the fluid rate increases, as shown in Fig. 12. It is caused by the frequency increase of separation of vortex structures from the leaflets of the valve with increasing flow velocity through this valve. Curve *1* represents the pure water flow through the open valve, curve *2* – the glycerin solution flow with a kinematic viscosity of 4.3ν, also through the open valve, curve *3* – the pure water flow through the semi-closed valve and curve *4* – the glycerin solution flow with a kinematic viscosity of 4.3ν through a semi-closed valve. Thus, near the side jet in the near wake of a bileaflet valve, the vortex shedding frequency is (1.2–1.3 times) higher for the pure water flow than for the glycerin solution flow with a kinematic viscosity of 4.3ν.

The ratio of spectral levels of pressure fluctuations in the near wake of the side jet of the glycerin solution to the pure water flow through a semi-closed mechanical bileaflet mitral valve for various concentrations of glycerin solution and fluid rate is shown in Fig. 13. The results, which are presented

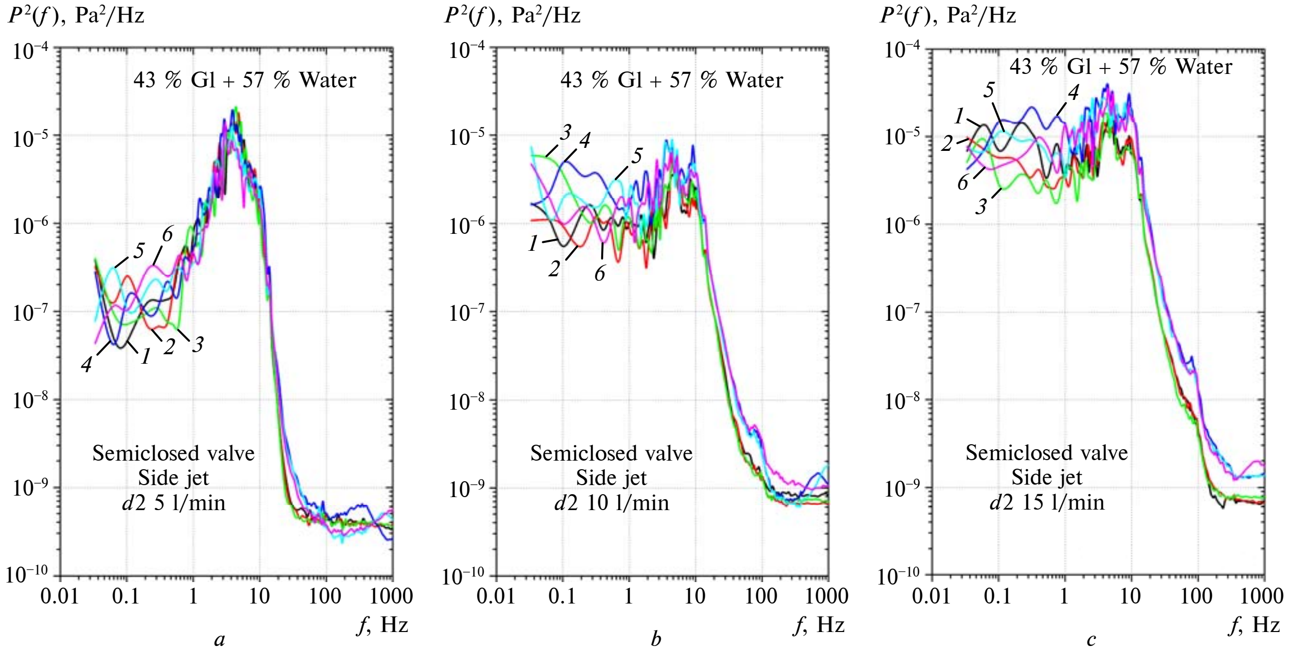


Fig. 11. Spectral power densities of the pressure fluctuations for semi-closed valve: *a* – Q = 5 l/min, *b* – Q = 10 l/min, *c* – Q = 15 l/min

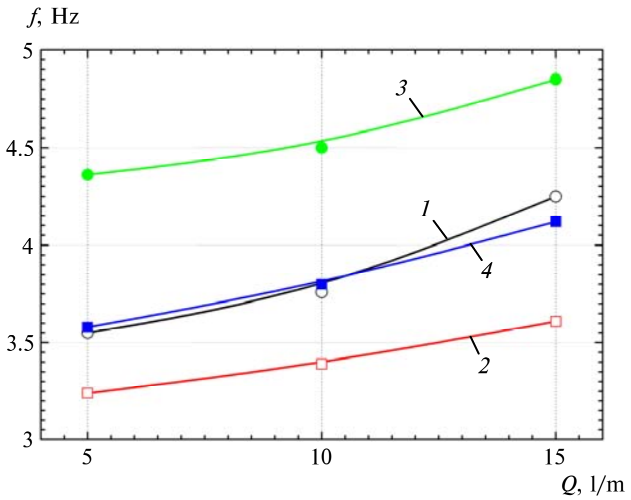


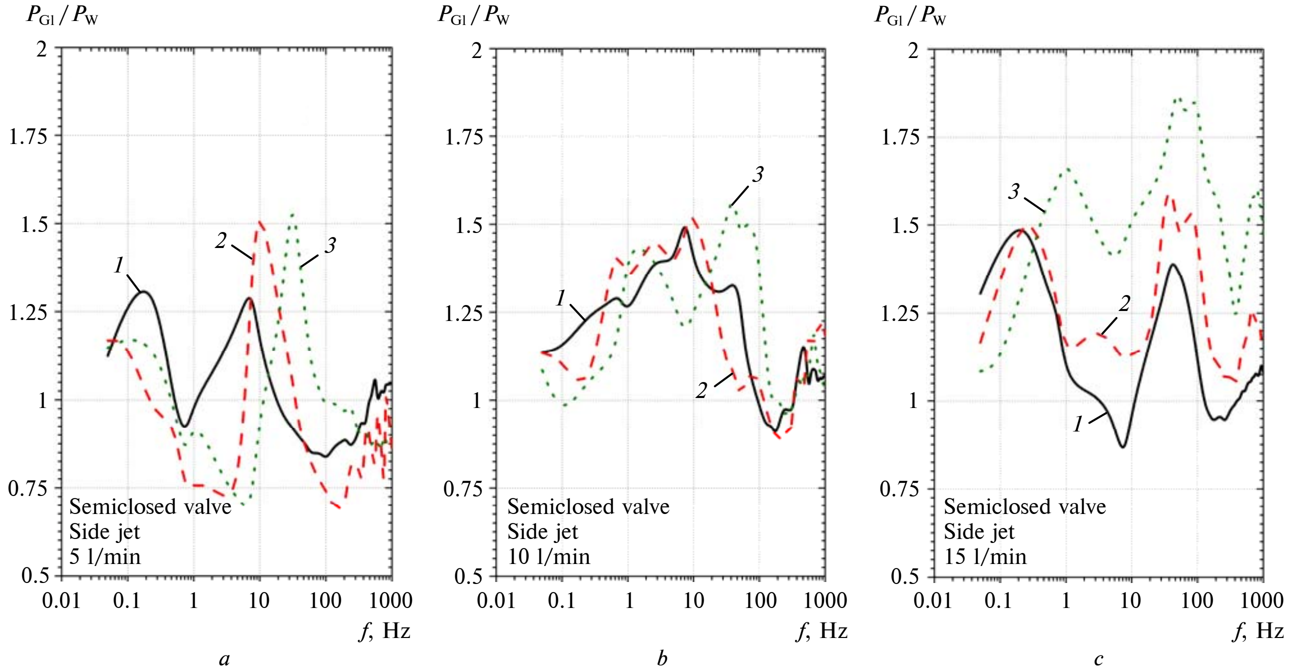
Fig. 12. Frequency of maxima of pressure fluctuations

in Fig. 13, *a*, were measured for fluid rate of pure water and glycerin solution $Q = 5$ l/min, in Fig. 13, *b* — for $Q = 10$ l/min and in Fig. 13, *c* — for $Q = 15$ l/min. Curve *1* represents the glycerin solution flow with a kinematic viscosity of 3.2ν, curve *2* — the glycerin solution flow with a kinematic viscosity of 3.8ν, and curve *3* — the glycerin solution flow with a kinematic viscosity of 4.3ν. For the low fluid rate, the spectral levels of the hydrodynamic noise in the near wake of the side jet of the glycerin solution are lower than for water flow in the frequency ranges from 1 to 7-8 Hz and from 100 to 1000 Hz. For higher fluid rates, the spectral components of the hydrodynamic noise in the near wake of the side jet of the glycerin solution of the semi-closed mitral valve are higher than that of pure water. The greatest difference in the spectral levels is observed in the frequency range from 10 to 100 Hz. At the same time, as the fluid rate and the concentration of the glycerin solution increase, the maxima of spectral levels are shifted to higher frequencies. The greatest difference (1.5—1.8 times) in the spectral components of the hydrodynamic noise of the glycerin solution and pure water are observed at the maximum fluid rate (see, Fig. 13, *c*).

Conclusions

It's found that in stream conditions of pure water, the integral characteristics of the pressure field are lower than in stream conditions of the aqueous glycerin solution. As glycerin concentration in the solution increases, average pressures and especially RMS pressure fluctuations increase. The mean values of pressure and RMS values of pressure fluctuations near the side jet of the semi-closed valve are higher than near the side jet of the open valve.

It's observed that the spectral levels of hydrodynamic noise increase both in the low-frequency region and in the high-frequency region as the fluid rate increases. This indicates that the intensity of large-scale vortex structures (generating low-frequency pressure fluctuations) and small-scale eddies that are separated from the leaflets of the valve during fluid flow through the open or semi-closed valve is increased. It's discovered that near the side jet in



a *b* *c*

Fig. 13. Ratio of spectral levels of pressure fluctuations: *a* — $Q = 5$ l/min, *b* — $Q = 10$ l/min, *c* — $Q = 15$ l/min

the near wake of a bileaflet valve, the vortex shedding frequency is (1.2—1.3 times) higher for the pure water flow than for the glycerin solution flow with a kinematic viscosity of 4.3ν.

It's registered that the spectral levels of the hydrodynamic noise in the near wake of the side jet of the glycerin solution are lower than for water flow in the frequency ranges from 1 to 7-8 Hz and from 100 to 1000 Hz for fluid rate 5 l/min. For higher fluid rates, the spectral components of the hydrodynamic noise in the near wake of the side jet of the glycerin solution of the semi-closed mitral valve are higher than that of pure water. The greatest difference (1.5—1.8 times) in the spectral levels is observed in the frequency range from 10 to 100 Hz at the fluid rate 15 l/min.

In order to develop effective diagnostic tools for the mechanical bileaflet heart valve operation for subsequent research, it is necessary to investigate the fluid viscosity effect on the hydroacoustic characteristics of jets for pulsed flow through a semi-closed and open prosthetic bileaflet heart valve that corresponds to the cardiac cycle of the heart.

Acknowledgements

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ВПЛИВ В’ЯЗКОСТІ РІДИНИ НА ШУМ ДВОПЕЛЮСТКОВОГО ШТУЧНОГО СЕРЦЕВОГО КЛАПАНА

Проблематика. Числове моделювання та експериментальні дослідження були використані як потужні інструменти, щоб зрозуміти і передбачити поведінку і механіку функціонування природних клапанів серця та їх протезів у природних і патологічних станах. Такі дослідження допомагають оцінити ефективність клапанів, їх дизайн і результати хірургічних процедур, щоб діагностувати нормальне і порушене функціонування серцевих клапанів. Актуальною є проблема створення більш надійних методів та інструментів, необхідних для діагностики умов роботи механічних клапанів серця.

Мета дослідження. Вивчення впливу в’язкості рідини на гідроакустичні характеристики струменів, які витікають із напівзакритого і відкритого механічного двопелюсткового серцевого клапана; вивчення можливості використання гідроакустичних вимірювальних приладів як діагностичного обладнання для визначення умов роботи двопелюсткового штучного клапана серця.

Методика реалізації. Експериментальне дослідження проводилося за допомогою гідроакустичних вимірювань гідродинамічного шуму в ближньому сліду бічного і центрального струменя розчину гліцерину і течії чистої води нижче за потоком від двопелюсткового штучного серцевого клапана.

Результати дослідження. Експериментально визначено вплив в’язкості рідини на гідроакустичні характеристики струменів, які витікають із напівзакритого і відкритого механічного двопелюсткового серцевого клапана. Виявлено інтегральні та спектральні характеристики гідродинамічного шуму струменів розчину гліцерину і течії чистої води нижче за потоком від двопелюсткового мітрального клапана серця для різних витрат рідини.

Висновки. В умовах потоку чистої води інтегральні характеристики поля тиску менші, ніж в умовах потоку водного розчину гліцерину. При підвищенні концентрації гліцерину в розчині середній тиск і особливо середньоквадратичні значення пульсацій тиску збільшуються. Спектральні рівні гідродинамічного шуму в ближньому сліду бічного струменя розчину гліцерину нижчі, ніж для потоку води в діапазонах частот від 1 до 7-8 Гц і від 100 до 1000 Гц для витрати рідини 5 л/хв. Для більш високих витрат рідини спектральні компоненти гідродинамічного шуму в ближньому сліду бічного струменя гліцеринового розчину напівзакритого мітрального клапана вищі, ніж для чистої води. Найбільша різниця (в 1,5–1,8 разу) – у спектральних рівнях спостерігається в діапазоні частот від 10 до 100 Гц для витрати рідини 15 л/хв.

Ключові слова: штучний двопелюстковий клапан серця; кінематична в’язкість; гідроакустичні вимірювання; пульсації тиску.

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ВЛИЯНИЕ ВЯЗКОСТИ ЖИДКОСТИ НА ШУМ ДВУЛЕПЕСТКОВОГО ИСКУССТВЕННОГО СЕРДЕЧНОГО КЛАПАНА

Проблематика. Численное моделирование и экспериментальные исследования использованы в качестве мощных инструментов для понимания и прогнозирования поведения и механики функционирования естественных клапанов сердца и их протезов в естественных и патологических состояниях. Такие исследования помогают оценить эффективность клапанов, их конструкцию и результаты хирургических процедур для диагностики нормального и нарушенного функционирования сердечных клапанов. Существует реальная проблема в создании более надежных методов и инструментов для диагностики условий работы механических сердечных клапанов.

Цель исследования. Изучение влияния вязкости жидкости на гидроакустические характеристики струй, которые вытекают из полузакрытого и открытого механического двулепесткового клапана сердца; изучение возможности использования гидроакустических измерительных средств в качестве диагностического оборудования для определения условий работы двулепесткового искусственного клапана сердца.

Методика реализации. Экспериментальное исследование проводилось с помощью гидроакустических измерений гидродинамических шумов в ближнем следе боковой и центральной струй раствора глицерина и течения чистой воды ниже по потоку от искусственного двулепесткового клапана сердца.

Результаты исследования. Экспериментально определено влияние вязкости жидкости на гидроакустические характеристики струй, вытекающих из полузакрытого и открытого механического двулепесткового клапана сердца. Обнаружены интегральные и спектральные характеристики гидродинамического шума струй глицеринового раствора и течения чистой воды ниже по потоку от двулепесткового митрального клапана сердца при различном расходе жидкости.

Выводы. В условиях течения чистой воды интегральные характеристики поля давления меньше, чем в условиях течения водного раствора глицерина. С увеличением концентрации глицерина в растворе средние давления и особенно среднеквадратичные значения пульсаций давления увеличиваются. Спектральные уровни гидродинамического шума в ближнем следе боковой струи раствора глицерина ниже, чем для потока воды в частотных диапазонах от 1 до 7-8 Гц и от 100 до 1000 Гц для расхода жидкости 5 л/мин. Для более высоких расходов жидкости спектральные компоненты гидродинамического шума в ближнем следе боковой струи раствора глицерина полузакрытого митрального клапана выше, чем для чистой воды. Наибольшая разница (в 1,5–1,8 раза) в спектральных уровнях наблюдается в диапазоне частот от 10 до 100 Гц для расхода жидкости 15 л/мин.

Ключевые слова: искусственный двулепестковый клапан сердца; кинематическая вязкость; гидроакустические измерения; пульсации давления.

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