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SIMULATION OF MUFFLER PARAMETERS IN VENTILATION CHANNELS OF VENTILATORS

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During long-term observation of the operation of the ventilator (artificial lung ventilation) of the UVENT-T model, a violation of repeatability was noticed under the same operating conditions. That is, on some devices of this particular model, the air flow sensor under the same conditions showed different values when repeating the measurements. Through experiments, it was established that this is caused by the unevenness of the air flow inside the ventilation channels of the ventilator, which is most likely caused by the design of the silencers installed there.

The article highlights the process of research and modeling of air flow in ventilation channels of ventilators of the apparatus due to the manufacture of several test variants of muffler designs, which should solve the problem of various deviations of flow measurements. The main idea was to change the number and size of the muffler holes. Obviously, the 5 holes of 2 mm scattered the air flow too much, due to which there was an increased risk of turbulence in the air flow, which could have caused the unevenness of its measurements. Therefore, on all new mufflers, the holes were reduced to 1 mm, but their number was increased by 2 times. In total, 6 design options were obtained. All 6 options were designed in CAD SolidWorks, and flow simulation was also carried out for test models. According to the results of air flow measurements, graphic dependencies were obtained for each of the silencer samples, namely the integral of the absolute error of the flow measurement, the integral of the flow noise power, the integral of the acoustic noise power and the maximum absolute error of the flow measurement.

In the future, it is proposed to develop a mathematical model of laminar air flow in a ventilator taking into account new designs of silencers, as well as to develop software for testing according to the developed algorithm and model. Conduct experimental testing of designed mufflers, as well as evaluate the results of the experiment. According to the research results, a conclusion will be made about the most effective muffler design, and its design will be used in the production of ventilators.

Keywords: *ventilator; air flow measurement; three-dimensional modeling of air flow; noise reduction; gas flow pressure reduction.*

Introduction

Testing the effectiveness of noise suppressors in ventilation channels of ventilators is important to ensure the safety and comfort of patients receiving treatment in intensive care [1]. Noise suppressors are installed in ventilation systems and respiratory support devices in order to reduce the level of noise that can arise from moving parts of ventilation systems and devices. The noise can be quite unpleasant for patients who are in a state of serious illness and stress. Testing of silencers includes measuring the noise level at various points of the ventilation system and comparing these data with the requirements of standards and recommendations [2]. This allows you to make sure that the noise suppressors are really effective and meet the requirements of patient safety and comfort.

In addition, testing the effectiveness of silencers helps ensure the safety of medical personnel working with ventilation equipment. High noise levels can have a negative impact on the health and mental state of medical personnel, which can lead to errors and accidents. Thus, testing the effectiveness of noise silencers in ventilation channels of ventilators and respiratory support devices is an important procedure to ensure the safety and comfort of patients and medical personnel [3].

One of the recent works of the group of authors [4], investigated the flow of air in the ventilation channels of artificial lung ventilation unit depending on the particle size and flow rate, where the authors claim that their results can be useful for development of effective ventilation systems in hospitals and other medical institutions.

In another work [5], the authors investigated the influence of the design and dimensions of the ventilation channels on the distribution of particles in the air flow. The authors found that the optimal design of ventilation channels can reduce the concentration of harmful substances in the air flow and increase the efficiency of ventilation.

Thus, there is a significant amount of work, where the author teams offer different solutions to the task of improving the operation of ventilators based on their own experimental research, modeling of structures, data processing and analysis of results.

Description of manufactured prototypes and test stand

In the course of solving the task of equalizing the air flow in ventilators, 6 prototypes of ventilation duct mufflers were made. All 6 structures of muffler prototypes are shown in Fig. 1.

Fig. 1. Prototypes of designs of various models of mufflers

All prototypes are made on the basis of one base, which has 8 through holes for 1 mm each around the circle, three of them are additional in the middle. Two mufflers have a lower height, and therefore, correspondingly, a shorter hole length. The other two prototypes have a conical cut, which was proposed and described in [6].

In order to bring the test results as close as possible to the real operating conditions of the device, it was decided not to create any artificial channels, but to use the ventilator (artificial lung ventilation) device directly. Since such mufflers are designed for the oxygen pneumatic path, the UVENT-T device was used for testing. This is an expert class ventilator with a built-in turbine for respiratory support of newborns, children and adults. The described device was taken out of the case ("disassembled"), and the display was also connected. The housing had to be removed to access the turbine pneumatic path and the oxygen path, which can be seen in Fig. 2.

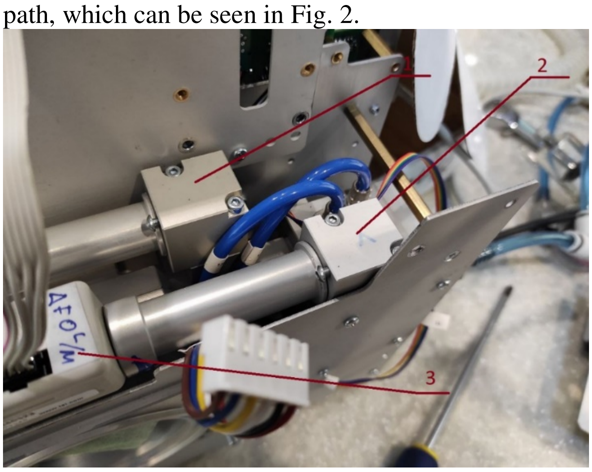


Fig. 2. Pneumatic blocks of oxygen and air tracts of the UVENT-T ventilator

In fig. 2: pos. 1 – corner pipe and part of the oxygen pneumatic tract (it is here that the muffler under development, shown in Fig. 3, is located), pos. 2 – angle pipe and part of the pneumatic path of the turbine, pos. 3 – one of the two air (or oxygen) flow sensors, which are located on both tracts.

Structurally, for greater reliability of the ventilator and measurement accuracy, different flow sensors are installed on the two pneumatic paths. In Figure 2, position 3 is the air flow sensor from the TSI company. A flow sensor produced by the Sensirion company is used on the pneumatic oxygen path, which will be taken into account, when developing an algorithm for testing muffler prototypes [7].

In Fig. 3, the location of the muffler in the pneumatic path of the turbine is marked with a red circle.

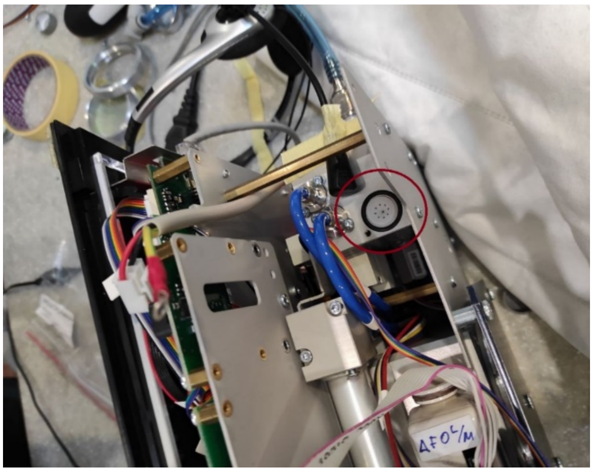


Fig. 3. Location of the muffler under development inside the angle duct of the oxygen pneumatic tract

Development of an algorithm for testing silencers of ventilation channels

Based on the technical requirements for the functioning of mufflers, the following algorithm for their compliance testing was developed.

First of all, it is necessary to check the noise of the air flow. To do this, it is necessary to gradually open the air supply valve with a certain step during a certain time, and also take data from the flow sensor. Since there are different flow sensors, the test must be repeated on the TSI sensor as well as on the Sensirion sensor in order to exclude the possible influence of sensor error on the measurement results.

Also, it is necessary to separately measure the acoustic noise of the tract with different prototypes of mufflers using a microphone.

To process the signals, as well as their visualization, a program was created in the Matlab system (a fragment of the interface screenshot can be seen in Fig. 4), since the library for reading data from ventilators is compatible with this system [8].

As a result, it was decided to record and visualize for comparison the integral of the absolute error of the flow measurement in the range of 0-100 l/min (with a flow increase step of 0.5 l/min every second), the integral of the flow noise power, the integral of the acoustic noise power at frequencies of 500 - 20000 Hz at a flow of 100 l/min, as well as the maximum absolute error of the flow measurement in the direction of under and over values.

Where in Fig. 4. 1 - selection of the valve through which the air will be supplied (in our case, the 8B valve is absent, since the device with a turbine is used, which does not have a separate air valve, instead, the turbine itself is used, and the turbine itself is silenced so as not to affect the flow that the program adjusts with the gradual opening of the valve 8A), 2 – the step of increasing the flow every second, 3 – the initial air flow, 4 – the final air flow value, 5 – switch for starting the program, 6 – choosing one of the two sensors for data recording.

Test results

For clarity of the results, each of the manufactured models of silencers was assigned a conventional designation (Fig. 5). In addition, the current serial version, with 5 holes of 2 mm is designated as U0 and in case without muffler as A.

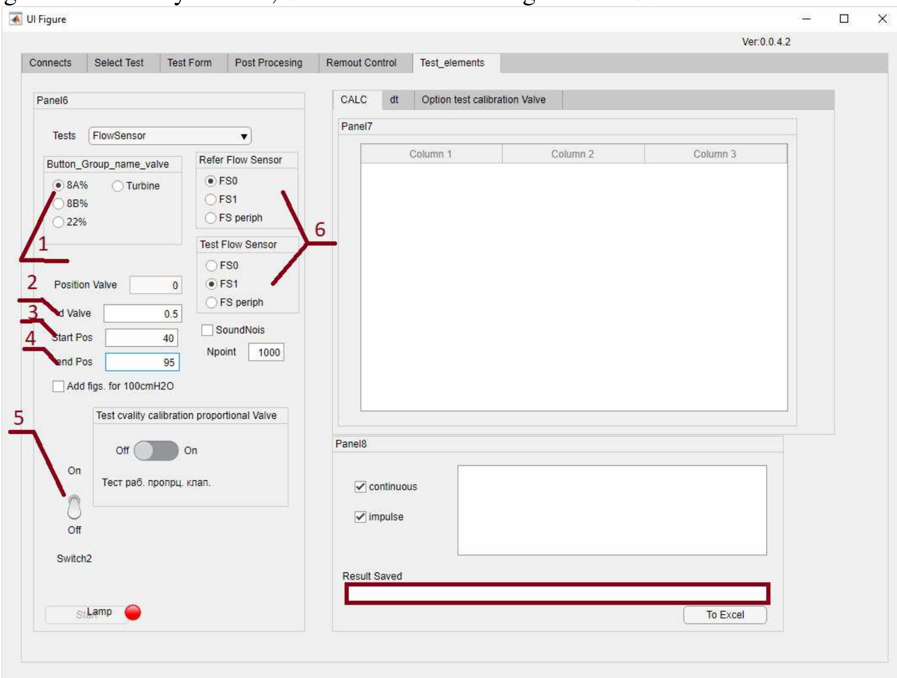
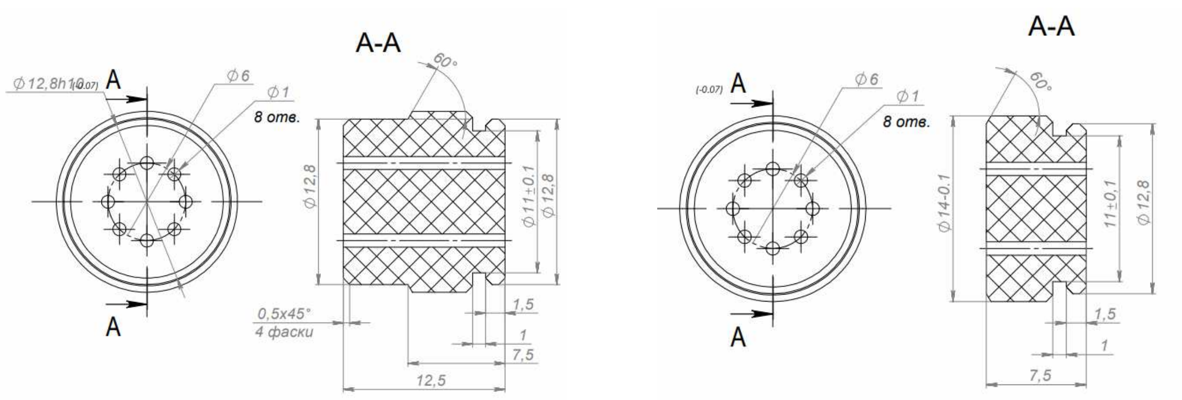


Fig. 4. Interface of the developed program

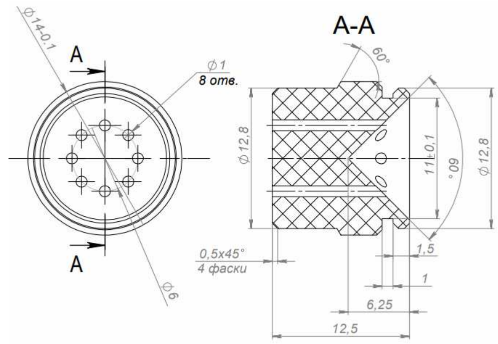
All the studied samples showed similar quantitative characteristics, both in terms of sound noise in the O2 (oxygen) pneumatic channel, and the effect on the accuracy of the subsequent measurement by TSI and Sensirion sensors: all mufflers approximately equally reduced the sound effects and increased the measurement accuracy compared to the condition without a muffler [7].

Moreover, according to the presented data, it is possible to single out the best characteristics of the muffler with the conventional designation U5 (Fig. 5-11). The graphs are built using Microsoft Excel program based on the data obtained as a result of air flow measurements using Matlab system. Formulas for calculating the obtained values for constructing graphs are specified for each graph separately.



a) b)

Fig. 5. Notations of Muffler (drawing): a) U1; b) U2; c) U3; d) U4; e) U5; f) U6



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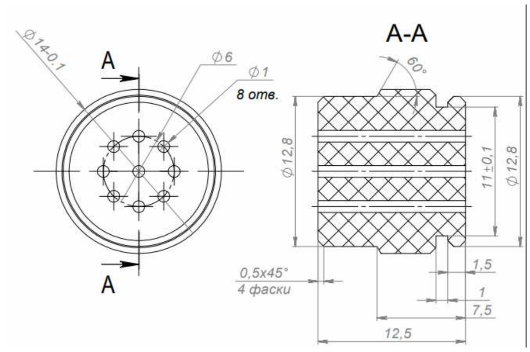

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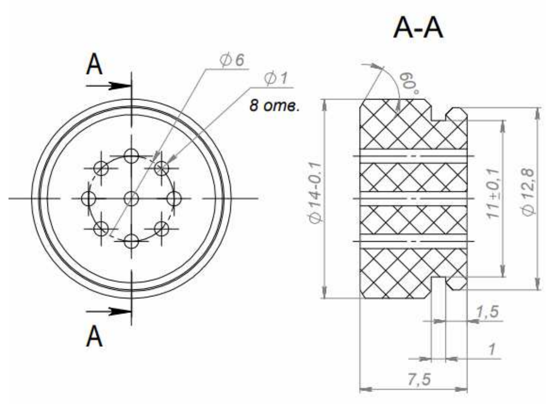

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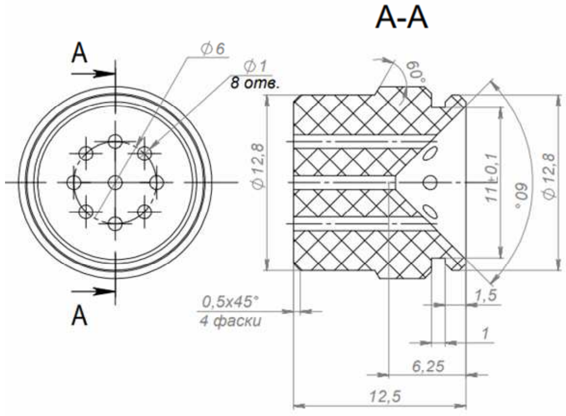

f)

Fig. 5. Notations of Muffler (drawing), where a) U1; b) U2; c) U3; d) U4; e) U5; f) U6 (continuation of Figure 5)

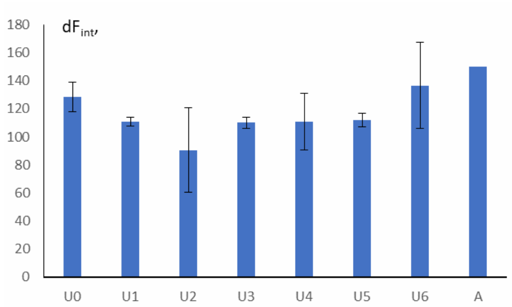

Fig. 6. Integral of the absolute error of flow measurement in the range of 0-100 l/min

$dF_{int} = \int_0^{100} |\Delta F| df$, where df – increase in flow of the control sensor, ΔF – absolute air flow measurement error

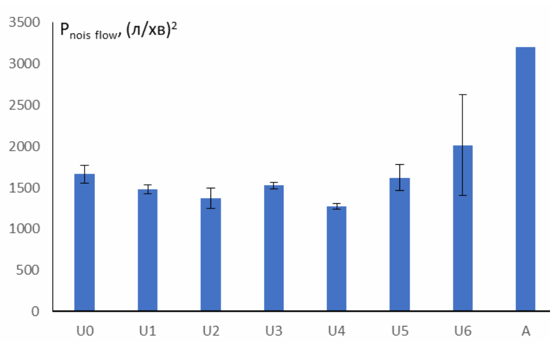

Fig. 7. Integral of the flow noise power (95% of the power is concentrated in the range of 0-100 Hz)

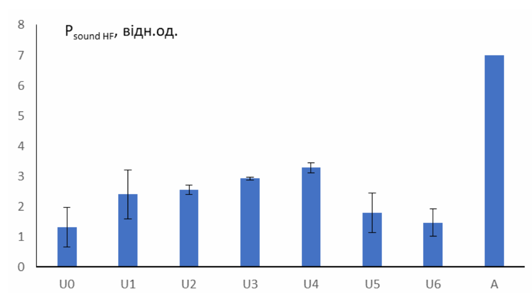

Fig. 8. Integral of acoustic noise power at frequencies from 500 to 20,000 Hz at a flow of 100 l/min

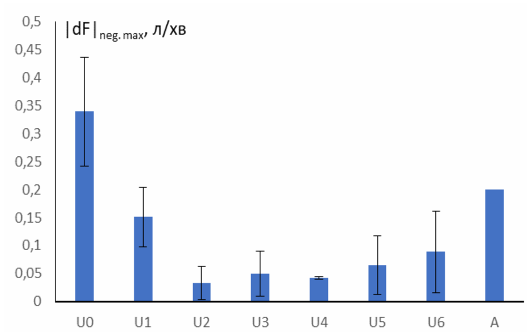

Fig. 9. The maximum absolute error of the flow measurement in the direction of underestimation of the values for the Sensirion sensor (observed in the range of 0-40 l/min, on average 20-40 l/min). For the TSI sensor, these errors are usually twice as high

The error is determined from the measured and averaged data after MatLAB measurement. The values for each sensor are given in Table 1. Where, averaged values of the maximum absolute error of flow measurement in the direction of underestimation of values are given in column 1; and in the direction of overestimation of values are given in column 2.

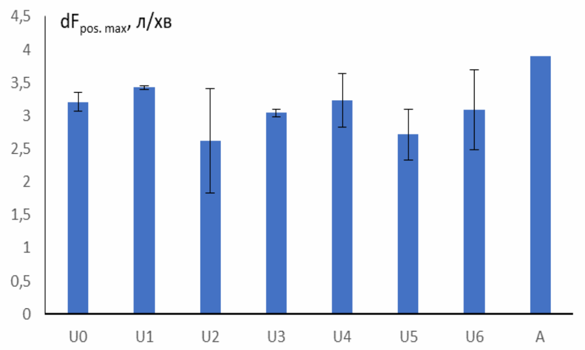

Fig. 10. The maximum absolute error of the flow measurement in the direction of overestimation of the values for the Sensirion sensor (observed in the range of 60-100 l/min, on average 80-90 l/min). For the TSI sensor, the data are almost identical

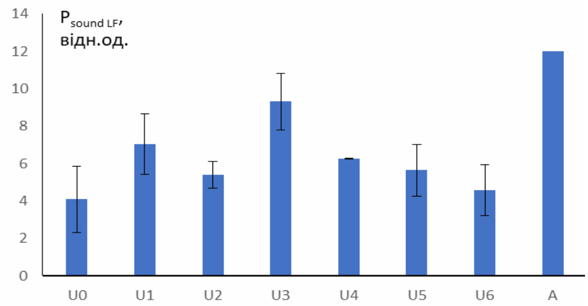

Fig. 11. Integral of acoustic noise power at frequencies from 0 to 500 Hz at a flow value of 100 l/min

Table 1. Averaged values of the maximum absolute error of flow measurement

Notation	1	2
U0	0,33943	3,210212
U1	0,150989	3,425408
U2	0,033128	2,622054
U3	0,05	3,045
U4	0,0425	3,231882
U5	0,064365	2,713126
U6	0,088481	3,086918

Prospects for further development directions

In the perspective of further research, a more in-depth study and analysis of various designs of silencers and their influence on the operation of the ventilator is planned [8]. As well as the development of a mathematical model of laminar air flow in ventilators taking into account the features of the proposed designs of silencers of ventilation channels, as well as the development of software for testing according to the developed algorithm and air flow model.

Conclusions

Testing the effectiveness of noise suppressors in the ventilation ducts of ventilator systems is usually performed to ensure the most comfortable and safe environment for a patient receiving artificial lung ventilation. Noise suppressors help to reduce the level of noise generated by the ventilation system, thereby reducing the negative impact of noise on the patient and providing favorable conditions for his recovery. In addition, checking the effectiveness of mufflers can help identify potential problems with the ventilation system and prevent them from developing further.

As a result of the research, a change in the design of the angle duct in the oxygen tract was revealed in comparison with the tested samples. Changing the shape of the angle guide to the old version did not significantly affect anything, but both angle guides have different pneumatic features.

In addition, a significant effect on the accuracy and repeatability of the measurements was observed depending on the nature of the junction of the flow straightener tube with the flow sensor. All muffler designs have approximately the same efficiency compared to the current production version, as well as measurements without a muffler. But in the muffler, the U5 variant is characterized by the smallest dependence on the position of installation in the oxygen path, as well as the smallest flow measurement error.

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МОДЕЛЮВАННЯ ПАРАМЕТРІВ ГЛУШНИКА В ВЕНТИЛЯЦІЙНИХ КАНАЛАХ ВЕНТИЛЯТОРІВ

Під час тривалого спостереження за роботою апарату штучної вентиляції легень (ШВЛ) моделі ЮВЕНТ-Т було помічено порушення повторюваності за однакових умов роботи. Тобто, на деяких апаратах саме цієї моделі датчик потоку повітря за однакових умов показував різні значення при повторюванні вимірювань. Шляхом експериментів було встановлено, що це викликано нерівномірністю потоку повітря всередині вентиляційних каналів апарату ШВЛ, яка спричинена конструкцією встановлених там глушників. Одним із напрямків досягнення мети в роботі було запропоновано проєктування глушників різних внутрішніх конфігурацій, які будуть мати різну пропускну здатність і відповідно формуватимуть потік повітря різної інтенсивності.

Стаття висвітлює процес дослідження та моделювання потоку повітря у вентиляційних каналах ШВЛ апарату внаслідок виготовлення кількох тестових варіантів конструкцій глушників, які мали б вирішити проблему різних показників вимірювань потоку. Основна ідея полягала в зміні кількості та розмірів отворів глушників. Вочевидь, п'ять отворів з діаметром 2 мм занадто сильно розсіювали потік повітря, через що був підвищений ризик турбулентності потоку повітря, що і могло спричинити нерівномірність його вимірювань. Тому на всіх нових глушниках діаметр отворів було зменшено до 1 мм, але збільшено їх кількість в 2 рази. Загалом отримано 6 варіантів конструкції. Всі 6 варіантів було спроектовано в САПР SolidWorks, а також здійснено моделювання потоку для тестових моделей. За результатами вимірювань потоку повітря були отримані графічні залежності для кожного із зразків глушника, а саме інтеграл абсолютної похибки вимірювання потоку, інтеграл потужності шуму потоку, інтеграл потужності акустичного шуму та максимальна абсолютна похибка вимірювання параметрів потоку.

У подальшому запропоновано розробити математичну модель ламінарного потоку повітря в апараті ШВЛ з урахуванням нових конструкцій глушників, а також створити програмне забезпечення для проведення тестування згідно розроблених алгоритму та моделі. Провести експериментальне тестування спроєктованих глушників, а також виконати оцінку результатів експерименту.

Ключові слова: ШВЛ апарат; вимірювання потоку повітря; тривимірне моделювання потоку повітря; зниження шуму; зниження тиску потоку газу.

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