Experimental study of a vacuum fluid transportation system

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Abstract. The authors proposed a method for calculation the main parameters of a vacuum fluid transportation system. In this paper a designed experimental stand for verification of the proposed method was proposed. Selection of the required equipment including vacuum pumps, differential pressure sensors and control valves was made. The body and covers of the pumped vacuum chamber were made using additive manufacturing techniques. A subsequent identification of the selected vacuum pumps’ characteristics was carried out taking into account the conductivity of the connecting pipelines. The pressure difference established in the chamber was calculated taking into account the relationship between the pumping speed and the pressure obtained during the experiment. As a result of the experiment, the pressure values in the mechanical and hydraulic compartments of the chamber, the volume of liquid pumped by the vacuum system were obtained.

1. Introduction
One of the most relevant problems in the areas of science and technology is the development of a system for transportation various types of fluid without changing its physical and biological characteristics. The authors proposed a method for calculation of the main parameters of a vacuum fluid transportation system. This system allows the movement of the liquid without contact with inorganic surfaces [1]. An experimental stand for the method’s verification was designed and manufactured.

2. Description of the design of the vacuum fluid transportation system
The photo of the developed system is shown in figure 1. The system works by creating a pressure difference between the hydraulic and the vacuum compartments separated by the elastic membrane. Two ports equipped with the solenoid valves VE5, VE6 for liquid input and discharge are located in the hydraulics compartment of the chamber. Similarly, vacuum chamber has two ports VE1, VE2 for pumping down and injecting gas into the chamber.

Pressure values in the vacuum and the hydraulic compartments of the chamber are measured by differential pressure sensors PDE2, PDE3.

During the suction stroke the chamber is pumped down by the vacuum pump and the elastic membrane is bent thus pulling the liquid from the input port.

During the discharge stroke the vacuum pump injects gas into the chamber and increases the pressure in it. The elastic membrane springs back to its undeformed shape because of the eliminated pressure difference between the hydraulic and the vacuum compartments and pushes out the liquid through the discharge port.

The valves VE1, VE2, VE3, VE4 are used for the connection of the different ports of the vacuum pump during the suction and discharge strokes.
3. Equipment selection

Some of the system components, such as the pumped vacuum chamber and the cover, were made using the additive technologies, figure 2. In the papers [2, 3] the authors used 3D printing to create system components for middle- and high-vacuum applications. Laminated application of the material may cause the micro gaps forming, this problem was taken into account this problem was dealt with by setting the slicer’s fill value to 100%. It makes possible to take the leakage flow value negligible compared with the pressure values in the vacuum compartment. The material of the chamber is PLA plastic.

The elastic membrane was made of silicone sheet, figure 3. Uniaxial tension tests were carried out and the Young’s modulus for the material used was calculated. The results are $E = 1.45$ MPa. The ultimate tensile strength is equal to 20 MPa. The modulus of elasticity was calculated based on specimen elongation under the applied load. It was not feasible to determine the transverse deformation of the specimen, hence for further calculations the value of the Poison coefficient will be used.

The pressure was measured using differential pressure sensors Freescale MPX5050DP with measuring range 0...50 KPa for vacuum compartment and Freescale MPX5010DP for the hydraulic compartment. The maximum measurement error of this sensors specified in the datasheet does not exceed 2.5 %.

The data collection was carried out using external 16-bit ADC (Analog-to-digital converter) Adafruit ADS1115 and Arduino Uno R3 microcontroller in conjunction with PLX-DAQ software.

The speed of the vacuum pump enabling the system to operate at required flowrate and create required pressure head is equal to $S_n = 0.744 \text{ L/min}$. The experimental stand included two vacuum pumps with pumping speed $-S_n = 5 \text{ L/min}$, $S_n = 3 \text{ L/min}$. The determination of the aggregated pumping speed of two parallel-connected pumps, taking into account the connecting pipelines, was carried out according to the following procedure. A chamber with known constant volume was
pumped down and the pumping curve was obtained. It was hypothesized that the pumping characteristic of the vacuum system "pumps - connecting pipelines" is described by the Gaussian distribution. A numerical method that takes into account the functional dependence of $S(p)$, figure 4, yields parameters of the Gaussian curve whereby the difference between the pump curve obtained experimentally and the theoretical pumping curve was no more than 1%.

![Figure 3. The elastic membrane.](image)

**Figure 3.** The elastic membrane.

![Figure 4. The pumping characteristic curve of the vacuum system "pumps - connecting pipelines".](image)

**Figure 4.** The pumping characteristic curve of the vacuum system "pumps - connecting pipelines".

The connecting diameter of the pipelines and branching fittings was determined by the connecting diameter of the solenoid valves available at the market, the diameter value $d$ is 5.5 mm. The tubes with the internal diameter $d_1 = 4$ mm were used as the connecting pipelines [4, 5]. The material of the tubes is PVC. The quick-disconnecting joint design is shown in figure 5.

The fact of the membrane’s buckling during the assembly was established [6, 7]. This is caused by the compressive forces influence in the place where the membrane is fixed. This disadvantage can be eliminated by creating pretension during the assembly to counteract the compressive forces. The relationship between the volume pumped down during the suction stroke depends on the degree to which the membrane is bent. Because of that fact the calculation included the initial membrane deflection caused by buckling [8]. The deflection value is 10.3 mm. The pumping curve obtained using the calculation method taking into account the membrane buckling, and the curve obtained experimentally is shown in figure 6. The chamber’s leak rate equal to $0.2 \text{ m}^3 \times \text{Pa} / \text{s}$ was taken into account.
Figure 5. Quick-disconnecting joint “valve-tube-fitting connection”.

Figure 6. The pumping curve obtained using the calculation and the curve obtained experimentally.

The data obtained theoretically and experimentally show reasonable agreement during the cycle, except for the period (3, 3.4) s. This can be explained by the fact that a membrane that has lost its stability can take a wavy form [9] during the injection process. In the improved model of the installation, it is proposed to use a polymethyl methacrylate vacuum chamber to obtain visual data of the membrane deformation during the system operation.

4. Conclusion
In this paper, an experimental stand was designed and manufactured to verify the developed method for calculation of the main parameters of a vacuum fluid transportation system. The results obtained theoretically and experimentally showed good agreement. A small discrepancy is caused by design deficiencies. To increase the agreement between the theoretical and experimental results mechanical properties of the membrane have to be determined with higher degree of accuracy. To that end we are going to use flexible strain gauges for large strain given that the Young’s modulus is much lower than that of steel. Furthermore fatigue life test of membrane should be carried out in order to determine the pump service life. To eliminate it some proposals have been put forward that will be implemented in the next version of the system.

References
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