SIMULAÇÃO NUMÉRICA E OTIMIZAÇÃO DO PROJETO DE UMA MEMBRANA CORRUGADA DO SENSOR DE PRESSÃO

NUMERICAL MODELING AND OPTIMIZATION OF THE DESIGN OF THE CORRUGATED PRESSURE SENSOR MEMBRANE

ЧИСЛЕННОЕ МОДЕЛИРОВАНИЕ И ОПТИМИЗАЦИЯ КОНСТРУКЦИИ ГОФРИРОВАННОЙ МЕМБРАНЫ ДАТЧИКА ДАВЛЕНИЯ

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RESUMO

Atualmente, os sistemas eletromecânicos são amplamente utilizados em tecnologia. Para o seu funcionamento, desempenham um papel importante os sensores, que são utilizados para medir os valores dos parâmetros físicos e convertê-los em sinais elétricos. O objetivo do estudo é determinar os limites de aplicabilidade de métodos analíticos e numéricos para o cálculo de tensões mecânicas e deflexões de membranas ao criar elementos de sensores de pressão. O trabalho descreve uma simulação numérica da membrana corrugada, que é utilizada em sensores de pressão. O cálculo foi realizado em uma formulação geométrica e fisicamente linear utilizando o complexo de hardware e software ANSYS. Os resultados do cálculo foram utilizados para otimizar o projeto, a fim de reduzir as tensões equivalentes máximas e aumentar o deslocamento do centro da membrana. Foi determinado que as membranas corrugadas desempenham um papel importante no funcionamento do dispositivo. Como a precisão da medição e confiabilidade do dispositivo dependem nelas, portanto, o grau de precisão de seu cálculo deve ser o mais alto possível. De acordo com os resultados do experimento, as deformações plásticas ainda ocorrem nas estruturas, o que é altamente indesejável para elementos elásticos.

Palavras-chave: *membrana corrugada, otimização, sensor de pressão, simulação numérica.*

ABSTRACT

Currently, electromechanical systems are widely used in technology. An important role is played by microsensors for measuring the values of physical parameters and converting them into electrical signals. The aim of the study is to determine the limits of applicability of analytical and numerical methods for calculating mechanical stresses and deflections of membranes when creating elements of pressure sensors. A numerical simulation of the corrugated membrane used in pressure sensors was carried out. The calculation was carried out in a geometrically and physically linear formulation using the ANSYS software and hardware complex. The results of the calculation were used to optimize the design in order to reduce the maximum equivalent stresses and increase the displacement of the center of the membrane. It has been determined that corrugated membranes play an important role in device operation. Since they depend on the accuracy of measurements and the reliability of the device, therefore, the degree of accuracy of their calculation should be as high as possible. After the experiment, it was established that plastic deformations still occur in structures, which is highly undesirable for elastic elements.

Keywords: *corrugated membrane, optimization, pressure sensor, numerical simulation.*

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АННОТАЦИЯ

В данный момент широкое распространение в технике получили электромеханические системы. В их работе важную роль играют датчики, которые используются для измерения значений физических параметров и преобразования их в электрические сигналы. Целью исследования является определение границ применимости аналитических и численных методов расчета механических напряжений и прогибов мембран при создании элементов датчиков давления. В работе проведено численное моделирование гофрированной мембраны, которая используется в датчиках давления. Расчет проводился в геометрически и физически линейной постановке с помощью программно-аппаратного комплекса ANSYS. Результаты расчета были использованы для оптимизации конструкции с целью снижения максимальных эквивалентных напряжений и увеличения перемещения центра мембраны. Определено, что гофрированные мембраны играют важную роль в работе устройств. Поскольку от них зависит точность измерений и надежность прибора, поэтому степень точности их расчета должна быть максимально высока. После проведенного эксперимента установлено, что в конструкциях все-таки возникают пластические деформации, что крайне нежелательно для упругих элементов.

Ключевые слова: *гофрированная мембрана, оптимизация, датчик давления, численное моделирование.*

INTRODUCTION

Nowadays, many tools for measuring the pressure of liquids and gases use corrugated membranes as elastic elements (Figure 1) (Axelrad and Emmerling, 1984). The main advantage of them is that they are able to work with significantly larger deflections than flat membranes. With the help of corrugated membranes, you can easily solve the problem of measuring values that are nonlinearly related to pressure (Lurie *et al.*, 2015; Kuznetsova *et al.*, 2015). By properly designing the membrane, you can get a characteristic that is linear in the measured parameter, and then the linearity of the scale of the device is achieved with the simplest kinematics of the mechanism. Usually, a rigid center is attached to the central part of the membrane, the stem of which serves to transfer movement from the membrane to the mechanism of the device (Shuai *et al.*, 2018; Liu *et al.*, 2016; Hau *et al.*, 2018; Fang *et al.*, 2016). Therefore, the key quality parameters are maximum displacement of the center of the membrane at working pressure and linearity of the output characteristic.

The purpose of this work is the strength calculation and optimization of the design of a commercially-manufactured corrugated membrane (Figure 2).

MATERIALS AND METHODS

In the calculation process, it is necessary to determine the maximum equivalent stresses in the structure, the maximum displacement of the center of the membrane, the nonlinearity of the output characteristic (Karuthedath and Schwesinger, 2018). To solve this problem, a mathematical model of a membrane without a stem was built (Figure 3). Due to the subtlety of the hard center, they can be neglected. The membrane thickness was 0.2 mm.

Physical properties of the material Steel 30 (Wegst, 2001): E = 200 GPa – Young's modulus, μ = 0,28 – Poisson's ratio, σ_t = 400 MPa – yield strength.

The design calculation scheme is shown in Figure 4. The fastening is attached according to the "flange clamp" principle (Hughes and Hinton, 1986; Zienkiewicz and Taylor, 2000). The pressure was applied to the corrugated part of the membrane. 0,8 MPa = 8 kgf / cm ^{2}. The calculation was carried out in a geometrically nonlinear and physically linear formulation in the ANSYS software package. For the calculation used element Shell208 (Inc, ANSYS…, 2013). The adequacy of the model was estimated by the rule of double thickening of the grid (Bich and Tung, 2011). During the calculation, the maximum displacement of the center of the membrane was determined (Figures 5, 6), which was 0.55 mm.

The maximum equivalent voltage was 922

MPa (Figures 7, 8). This suggests that we are moving into the area of plastic deformations, which is unacceptable when designing most structures (Song *et al.*, 2018). To determine the true value of mechanical stresses, it is necessary to include in the calculation a model of the structure's behavior beyond the yield point (Li *et al.*, 2003). Also, the residual thermal stresses after quenching and tempering will significantly influence the magnitude of the mechanical stresses. The output characteristic, the dependence of the deflection of the center of the membrane w0 on the magnitude of the applied pressure P, is shown in Figure 9. The magnitude of the nonlinearity is 6%.

RESULTS AND DISCUSSION:

The role of corrugated membranes in the operation of the device is very responsive. The accuracy of measurements and reliability of the device depend on them, and therefore the degree of accuracy of their calculation should be as high as possible (Khastan *et al.*, 2017; Huang *et al.*, 2015; Santorum *et al.*, 2018). Unfortunately, in practice, manufacturers often do not use the modern potential of computer complexes, but use classical approaches for calculation (Batoz *et al.*, 1976; Ashwell and Gallagher, 1976) or act empirically based on their experience. This leads to a decrease in the accuracy and reliability of measuring devices and an increase in the number of defective products (Cortez, 2014).

Nowadays, a calculating engineer has many software tools (Ansys, SolidWorks, Siemens NX, Nastran, Abaqus, CATIA) that allow high-precision numerical simulation of the structure under study, assessment of strength and rigidity, setting realistic.

Having obtained the calculation data, it became possible to solve the optimization problem in order to change the geometry of the structure to reduce the maximum equivalent stresses and increase the displacement of the center of the membrane. The coordinates of the points describing the membrane profile were chosen as project variables. The variable state was selected deflection of the membrane. The maximum equivalent stress in the structure was taken as the objective function. To perform optimization, an approximation method was used. As a result, variants of the membrane geometry were obtained (Figure 10), the maximum mechanical stresses in which were reduced compared with the initial geometry and the center movement was increased (Figure 11). For clarity, the comparative characteristics of the initial membrane and membranes obtained during the optimization are summarized in Table 1.

CONCLUSIONS:

Thus, a numerical simulation of a serially manufactured corrugated membrane was carried out. The calculation results showed that plastic deformations will occur in the structure, which is highly undesirable for elastic elements. In addition, two optimization models of membranes were obtained that exceed the initial design in quality parameters. The nonlinearity of the characteristics of all membranes is permissible and is not a key factor in the selection of the priority design.

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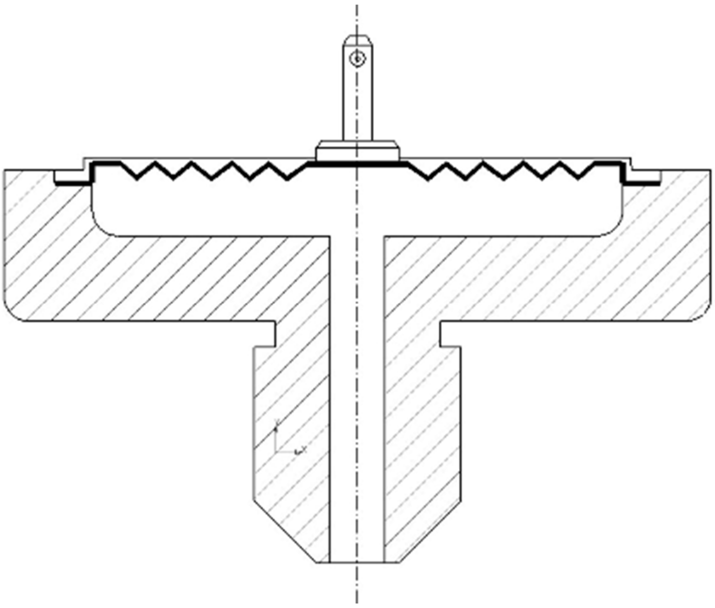

Figure 1*. Membrane sensing element with a single membrane mounted in the housing*

Figure 2*. Corrugated membrane*

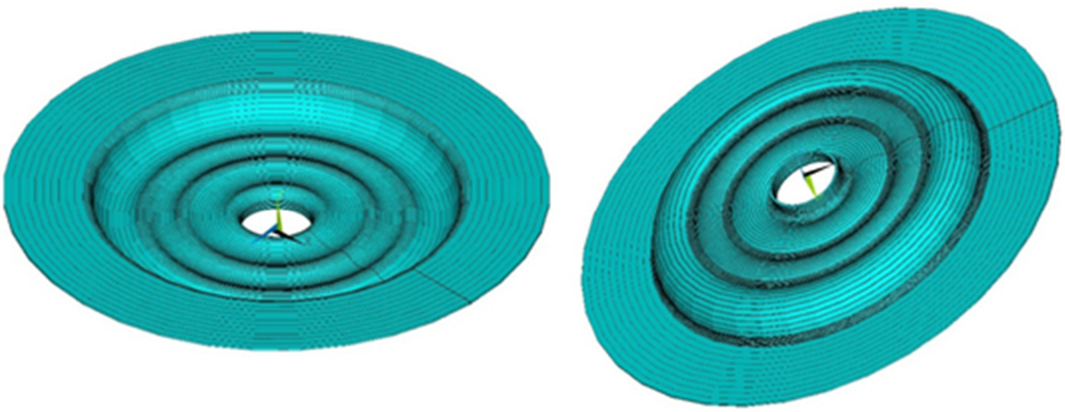

Figure 3*. A mathematical model of the membrane*

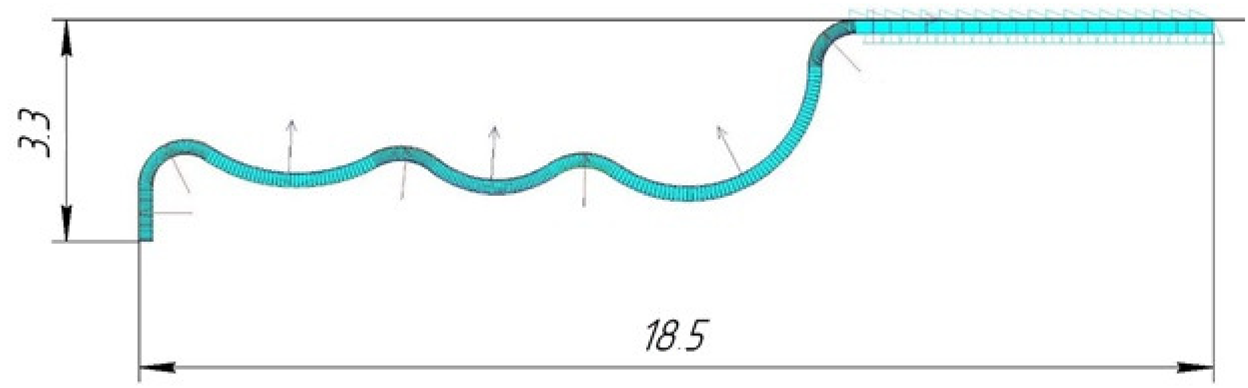

***Figure 4**. Design scheme*

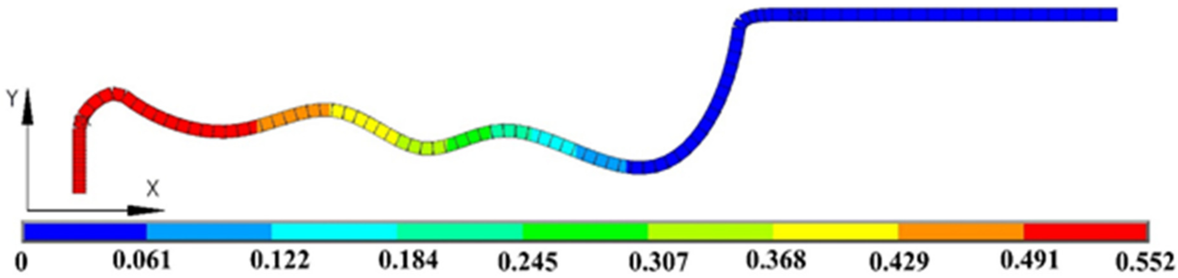

***Figure 5.** Nodal displacements in the Y direction in the structure, mm*

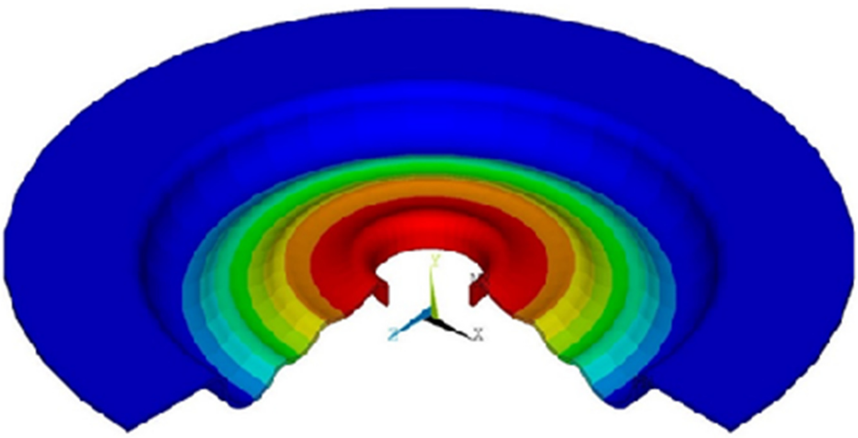

***Figure 6.** Displacement in the Y direction in the design*

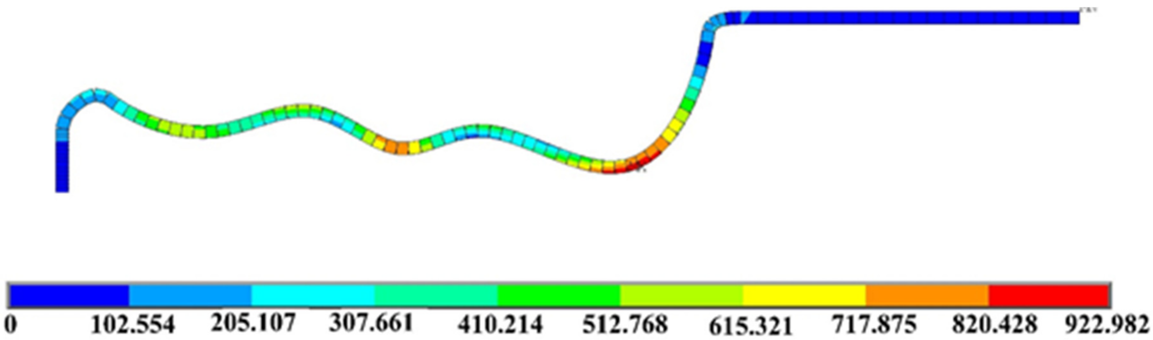

***Figure 7.** Equivalent stresses in construction, MPa*

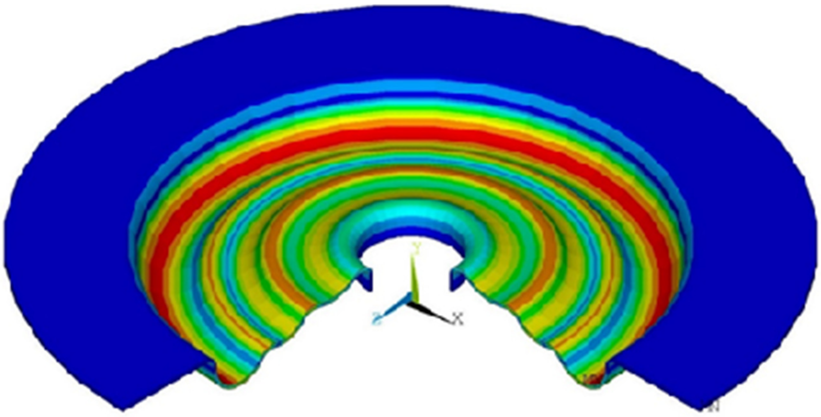

Figure 8. *Equivalent stresses in the structure*

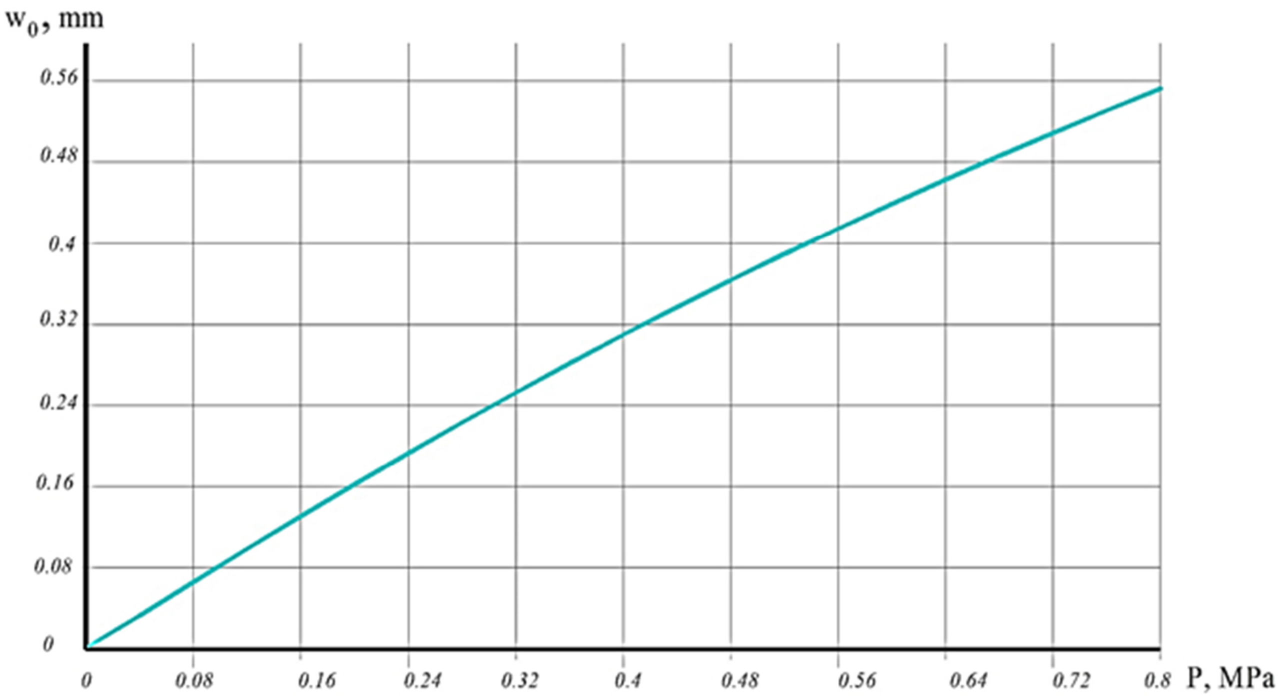

Figure 9. *Characteristics of the original membrane. Nonlinearity 6%*

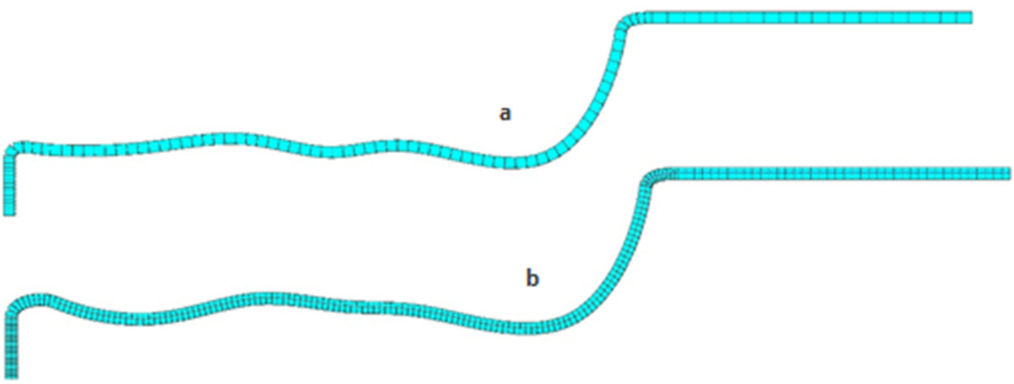

Figure 10. *Optimized membrane profile: a – no. one; b – membrane no. 2*

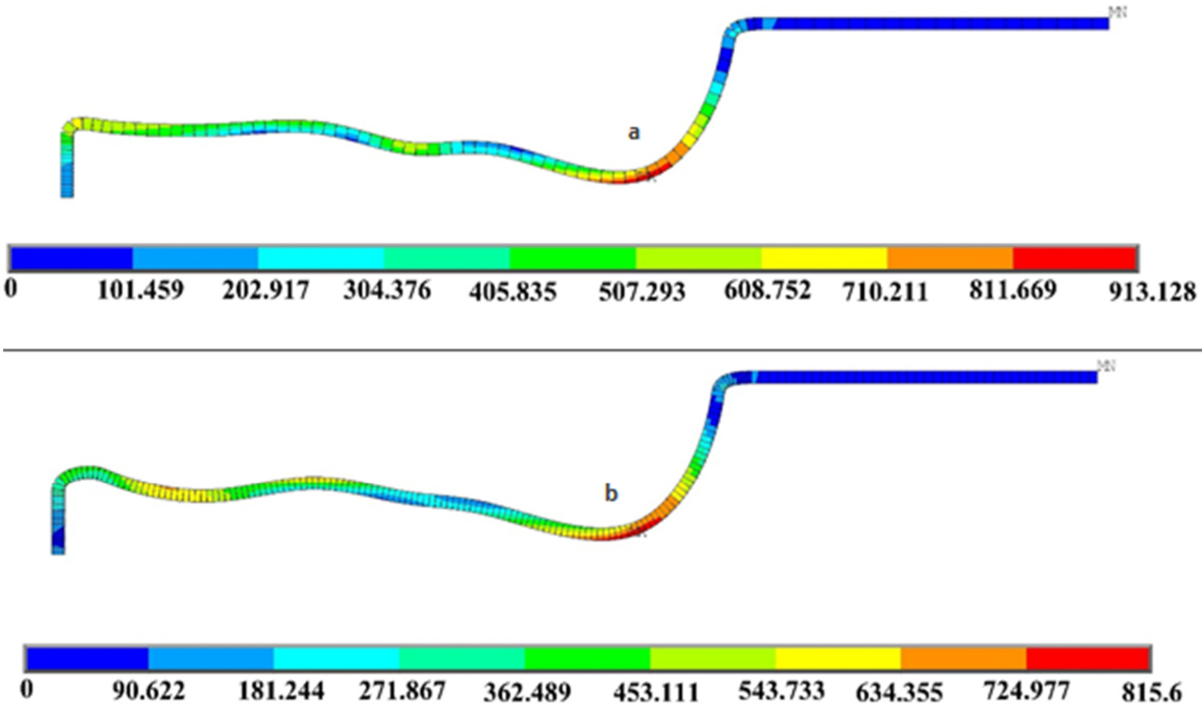

***Figure 11**. Equivalent stresses in MPa in an optimized membrane: a – membrane No. one; b – membrane no. 2*

***Table 1**. Comparative membrane analysis*

	Maximum equivalent voltage, MPa	Vertical movement of the center of the membrane, mm	Nonlinearity characteristics,%	The thickness of the membrane, mm
Original construction	923	0,55	6	0.2
Optimized membrane number 1	815	0,56	9	0.192
Optimized membrane number 2	913	0,63	8	0.188