MODELLING AND SIMULATION WITH FINE ELEMENT METHOD CONCERNING BEHAVIOR OF THE RADIAL CORRUGATED DIAPHRAGM

Florin Negoescu[1], Francisco Santos Martin[2]

[1]"Gheorghe Asachi" Technical University of Iasi-Romania, Department of Machine Manufacturing Technology
Blvd. D. Mangeron, No. 59A, 700050 Iasi, Romania
[2] University of Valladolid-Spain, Department of Materials Science and Metallurgical Engineering-Mechanical Engineering, Escuela de Ingenierías Industriales, Pº del Cauce 59. 47011 Valladolid, Spain

Corresponding author: Florin Negoescu, fnegoescu@gmail.com

Abstract: The purpose of the paper is to establish the way the corrugated metallic diaphragms with radial corrugations can be deformed by the influence of an equally spread pressure. The first part presents the analysis of the stress state and of the specific deformations, which appear in the diaphragm material, through an analysis in the nonlinear domain using the finite elements programme. The second part of the paper presents the influence on the magnitude of the von Mises equivalent stress of the amplitude and the number of corrugations, the thickness of the material, as well as the interactions of these factors. The results of the analysis constitute an estimative model for the experimental approach of the behavior of the radial corrugated diaphragms, also allowing the comparison of the results obtained by modeling, using the method of the finite elements with the experimental ones.
Key words: Finite element method, radial corrugated diaphragms, stress state, deforming state, equivalent von Mises stress, characterisc's diaphragm.

1. INTRODUCTION

The need to study the corrugated elastic diaphragms arises due to their use in advanced fields such as the aerospace and military industries and in the control and automation of the industrial processes. The elastic diaphragms are pieces of circular form on a planned or profiled surface, integrated in a contour, which, under the pressure applied on one face, gives visible and easily measurable distortions.

The functioning of the devices that have metallic diaphragms as the sensitive element is based on their elastic deformation under the influence of pressure or force. The metallic diaphragm is fixed on the contour by the body of the device, pressure or force being applied on one side of the diaphragm, leading to its elastic deformation. On the other side of the diaphragm, there is a rigid centre, whose movement depends on the arrow at the centre of the diaphragm. Thus, the movement of the rigid centre is the useful piece of information, depending on the value, which is to be measured (Demian, et al. 1994).

Compared to the other transducers such as Bourdon tubes, corrugated tubes and manometric tubes, the diaphragms were imposed by the ease of characteristic modelling, in certain applications such as measuring the pressure gauge, determining the speed and height of the planes. The theoretical research methods found in the specialized literature is based on theories advanced by the strength of materials such as flat plate theory and thin coating theory. The results were obtained based on simplifying working hypotheses and do not take into account all the factors that influence the characteristic.

The approach of the behavior of radial corrugated diaphragms represents a continuation of the research carried out by the authors for other types of diaphragms, such as those with a triangular profile, with a round profile or with a marginal corrugation (Negoescu and Santos Martin, 2014; Negoescu, et al. 2008; Negoescu and Axinte, 2007).

The technological process of diaphragm manufacture is complex, difficult and involves a high degree of material processing. The deformation is achieved by stretching the material of the semi-finished product, imposing the respect of the dimensions of the corrugations, so that it does not exceed the breaking strength of the material. Depending on the constructive parameters, the diaphragm corrugations can be obtained either from a single operation (hydraulic deformation) (Negoescu and Miron, 2007) or more operations (incremental deformation) (Coman, 2015; Negoescu and Dodun, 2007).

2. THE SIMULATION WITH FINITE ELEMENT METHOD OF THE RADIAL CORRUGATED DIAPHRAGM

The study of the special literature in order to establish the current stage of the research in the field of metallic corrugated diaphragms does not offer any information concerning the influences of the radial corrugations on this behavior. The optimization of the constructive parameters of the radial corrugated diaphragms is an important step in the design process of these elements, because it allows to obtaining quality diaphragms.

The simulation represents a technique of achieving the experiments with the aid of computers, which involves a utilization of the mathematical models that describe the behavior of the system in time.

The model used in the analysis with finite elements is an approximate model obtained by assembling the elements of finite components. The approximation involved is due, first of all, to the discretization operated on continuous structures, by representing them in the form of an assembly of parts, fine elements, interacting in a finite number of points, the nodes of the applied discretization. The analysis of the whole structure is reduced to the introduction of studies represented by the finite elements that make up the whole model attached to the structure. The values of the solution of the problem are calculated in nodes.

The present of the radial corrugation can drive to significant modifications in what concerning the behavior of metallic corrugated diaphragms (the arrows of deformation, the distribution stress of state in the material and the form of the feature.

We will present the results obtained by applying this method to the modelling of the behavior of radial diaphragms, under the action of a disruptive force. The first part presents the analysis of the stress state and of the specific deformations that appear in the diaphragm material, through an analysis in the nonlinear domain. Because the elastic diaphragms requirement must be below the material proportionality limit, the nonlinearity of the material is not of interest for this study, but only the geometric one. The fundamental particularity of the problems with geometric nonlinearity, also called problems with large displacements, is that the modification of the initial shape of the diaphragm is considered, as a result of displacements in the deformation process under the applied tasks.

The purpose of this analysis is to obtain a description of the distribution of stresses and deformations as accurately as possible, in the diaphragm material, representing an estimative model for the experimental approach.

In the analysis was taken into consideration the beryllium copper with the following mechanical characteristics: modulus of elasticity E =1.1·105MPa, Poisson coefficient υ=0.38 density ρ=8900Kg/m^3, flow limit = 980655·10^{2}MPa, breaking limit = 1.17678*10^{3}MPa. The diameter of the corrugated diaphragm is 80mm.

For discretization, finite elements of variable dimensions were used, depending on the importance of the study area and were automatically realized by the program. The diameter of the corrugated diaphragm is 80mm. For discretization, finite elements of variable size were use, depending on the importance of the study area and were automatically carried out by the program.

For the metal diaphragms used for the analysis, the following parameters were taken into account: the amplitude of the corrugations (A), the number of corrugations (n), the thickness of the material (t), the nature of the material and a maximum deformation pressure of 0.2bar. In order to simulate the behavior of radial corrugated diaphragms, the boundary conditions imposed on the diaphragm are the outer diameter of the diaphragm, whether is recessed, and for the center of the diaphragm, only movement in the Y-axis is allowed.

As unknowns of the problem, we are considering the displacements of the nodes that uniquely determine the stress state inside a finite element. Once the displacements on the nodes are known, the stresses can be calculated at the points of each element.

Following the post-processing of the analysis results, the following observations can be made:

-reaching the level of critical stress and thus the passage of the material in the plastic field, allows establishing the most burdened areas during operation;

-the results, although they have a realistic expression, cannot be close to the experimental ones, due to the differences existing between the real and the modelled system;

- the purpose of the present analysis is to obtain a description of the distribution of specific stresses and deformations, which will be a model for the experimental approach.

The analysis of the corrugated diaphragms in the nonlinear domain follows the stress state, the displacements and the specific deformations that occur in the body of the diaphragm in the following situations:

-at the level of the inner surface of the diaphragm, (the inner surface is the surface on which the deformation pressure acts);

-at the level of the outer surface of the diaphragm, (the outer surface is the surface that comes into contact with the displacement transducer elements).

2.1 Analysis of the stress state variation in the diaphragm material

The Figures 1, 2, 3 and 4 show the variations of the equivalent stresses according to the von Mises energy criterion obtained with the help of the analysis program by the finite element method, for a diaphragm with a radial corrugated subjected to a maximum pressure of 0.2bar.

Following the post-processing of the analysis results, the following observations can be made:

• As a result to the numerical analysis in the nonlinear domain, of the radial corrugated diaphragms, it is necessary first of all, the finding that, the maximum values of the equivalent stress are reached at the level of the corrugation peaks and have positive values corresponding to the stretching requirement;

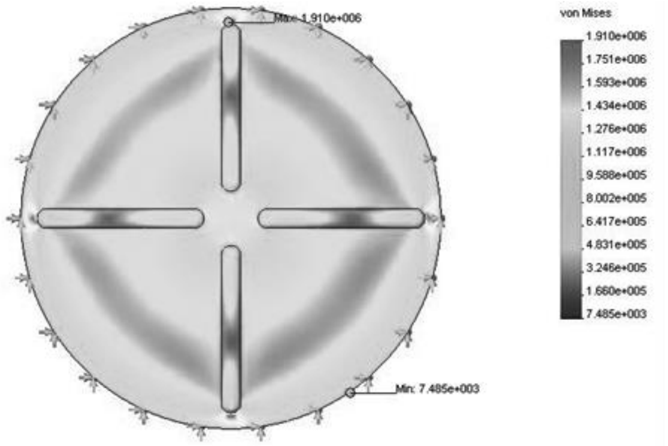

Fig. 1. Variation of equivalent stress in [MPa] according to the von Mises energy criterion at the outer surface level for four corrugations

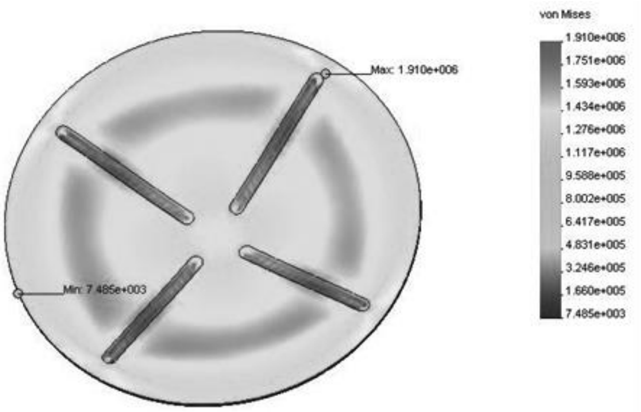

Fig. 2. Variation of equivalent stress in [MPa] according to the von Mises energy criterion at the inner surface level for four corrugations

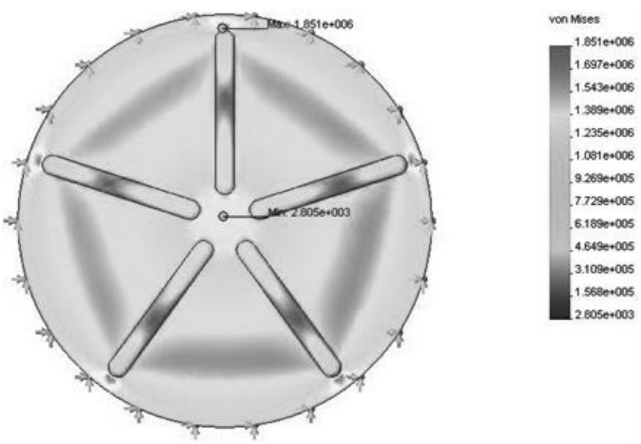

Fig. 3. Variation of equivalent stress in [MPa] according to the von Mises energy criterion at the outer surface level for five corrugations

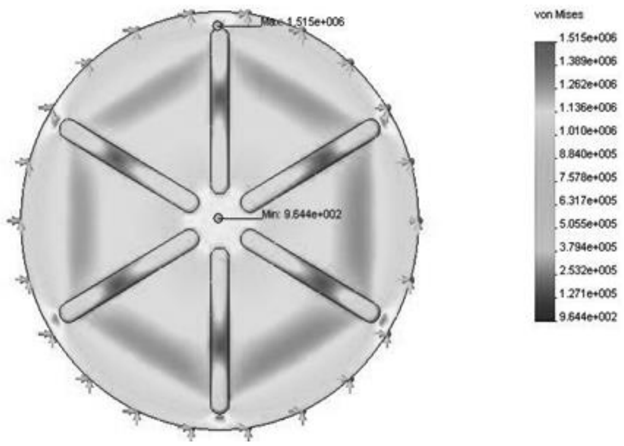

Fig. 4. Variation of equivalent stress in [MPa] according to the von Mises energy criterion at the outer surface level for six corrugations

• The determination of the tension state of the material in relation to the deformation pressure gives the possibility to choose the working range corresponding to each type of corrugation;

• The equivalent stresses that give rise to the material are corresponding to the elastic domain, so the diaphragms do not undergo plastic deformations for the studied pressure.

2.2 Modelling the deformation status of the diaphragm

The purpose of this analysis is to obtain as accurate a description as possible of the modification of the shape of the corrugated diaphragm under the action of an external pressure applied uniformly distributed on its surface and of the determination of the arrow with which it deforms.

In Figures 5, 6 and 7 are represented the variations and deformations obtained with the analysis program by the finite element method, for radial diaphragms with 4, 5 and 6 corrugations as a result of the action of the working pressure of 0.2bar.

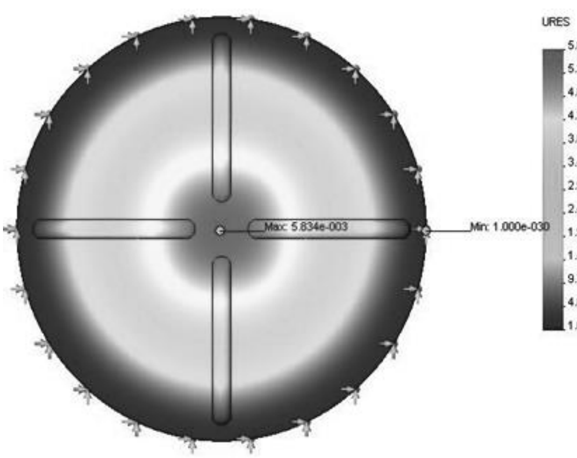

Fig. 5. Variation of deformations for the four corrugations

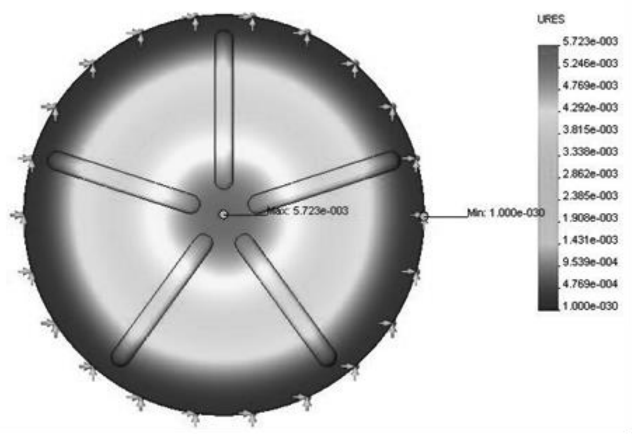

Fig. 6. Variation of deformations for the five corrugations

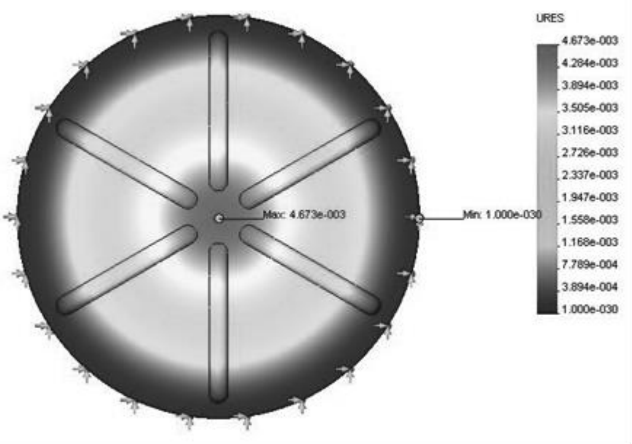

Fig. 7. Variation of deformations for the six corrugations

Following the post-processing of the analysis results, the following observations can be made:

- The obtained results will be used when comparing the experimental characteristic with the one resulting from modelling;
- From the analysis of these representations, one can easily find that the displacements, so the arrows reach maximum values in the center of the diaphragm. Also, it can be observed that, the areas near the embedding edge suffer small displacements compared to those in the center. It can be observed that the radial corrugated diaphragms have lowers displacement values compared to the circular corrugated diaphragms at the same deformation pressure value.

The characteristic of the elastic diaphragm can be expressed, depending on the actuation load, by a relation of displacement of the center of the diaphragm under the action of a uniformly distributed external pressure (Figure 8).

The graphical representation of the characteristic can be linear, named and constant, or non-linear. The non-linearity of the characteristic can be manifested throughout the domain or only on certain portions of it. Depending on the straight line that is taken into account, different definitions of the deviation from linearity are used:

- As a ratio between the maximum deviation and the reference range, considered according to the direction of the same coordinate axes;
- As a maximum value of the ratio between the deviation and the corresponding value of the measured size.

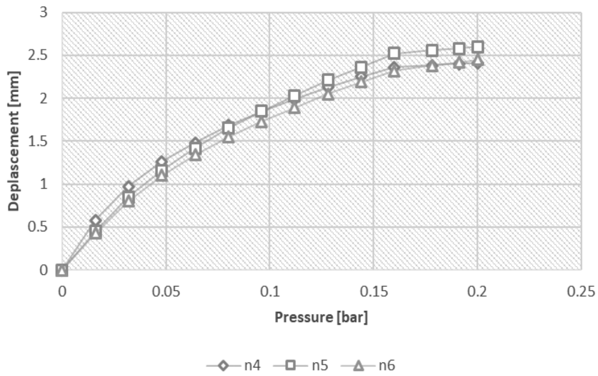

Fig. 8. Variation of deformations for diaphragms with four, five and six corrugations

From the analysis of these graphs it was observed that the crumbling of the material during the process of obtaining by cold plastic deformation of the corrugations, as well as the thermal treatment to which the diaphragm can be subjected, determines the modification of the initial mechanical characteristics of the material, in this case of the longitudinal elasticity module.

3. PROGRAMMING OF THE RESEARCH SETUP

In this paper, we adopt for studied influential geometric parameters have the radial corrugated diaphragms, the material thickness, the amplitude and the number of the corrugated, about the equivalent tension after his criterion von Mises consider in the Table 1, two values (levels) corresponding to each factor investigated.

Table 1. The factors and levels of test

The symbol	The factor of test	Level 1	Level 2	Unit of gauge
		-1	+1	
t	The thickness of the material	0.1	0.3	mm
A	The amplitude of the corrugations	1	1.5	mm
n	The number of the corrugattions	4	6	-

For the research, a complete orthogonal factorial plan was chosen, type 2^n (2^3=8 tests), for which the Yates algorithm is used, and the research scheduling is

performed according to the following Table 2, (Durivage, 2016). Use of the method of the experimental plans requires the use of notions such as: factor (variable or state acting on the studied system), response (the size that is measured to know the effect of factors on the system), the level of a factor (the values that the factor takes during the experiences) and significant factor or interaction (factor or interaction which by which modification leads to change of the response of the research system), (Ionescu and Amarandei, 2004).
In order to estimate the relative effects of the factors, their effect is compared. This comparison is easier if the results are present in the form of graphs in which the effects of the factors and interactions between them presented in Figure 9 are plotted.

Table 2. The matrix of experimentation

Number of attempts	The factors			The equivalent tension [MPa]
1	-1	-1	-1	242
2	-1	-1	+1	130.2
3	-1	+1	-1	238.3
4	-1	+1	+1	115.6
5	+1	-1	-1	231.2
6	+1	-1	+1	130.5
7	+1	+1	-1	263.1
8	+1	+1	+1	119.4

4. RESULTS AND DISCUSSIONS

In order to be able to decrease the values of the equivalent voltage, it is necessary to choose the number of corrugations at level 2, the amplitude of the corrugations at level 1 and the thickness of the material at level 1. In conclusion, it is recommended for the number of corrugations high values, and for the amplitude of the corrugations and the thickness of the material small values.

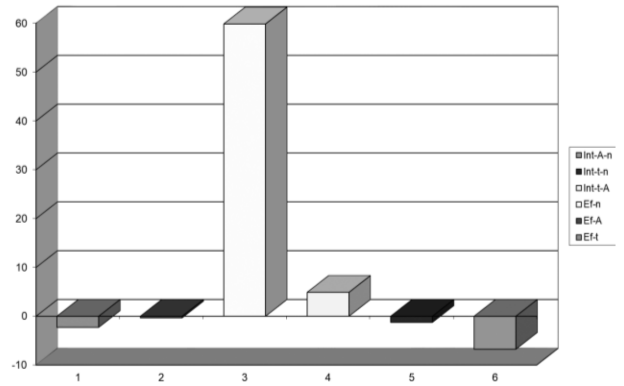

Fig. 9. Graphic representation of the effects and interactions at level 1 on the value of the equivalent stress

A graphical representation of the effects of factors and interactions on the equivalent stress is shown in Figures 10 and 11, according to the recommendations in the literature.
The effects of the other factors (the number of undulations and their amplitude) as well as the interactions with the other factors considered can be neglected;
From these graphs, it is observed that, between the 3 factors considered there are interactions, so the effect of each depends on the levels of the others. The largest interactions occur between the thickness of the material and the amplitude of the corrugations, and the weakest interaction being between the number of corrugations and the thickness of the material.

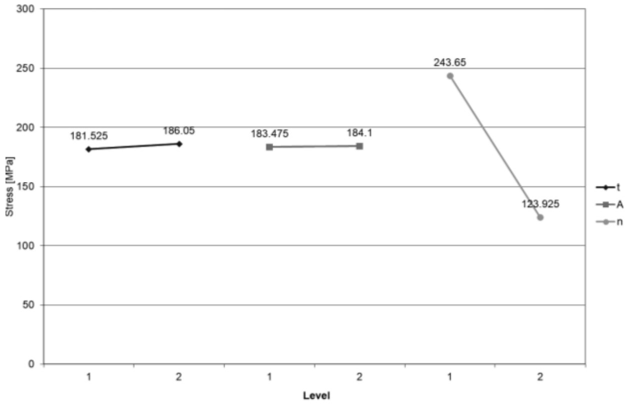

Fig. 10. The graphic representation of the effects about value of the equivalent stress

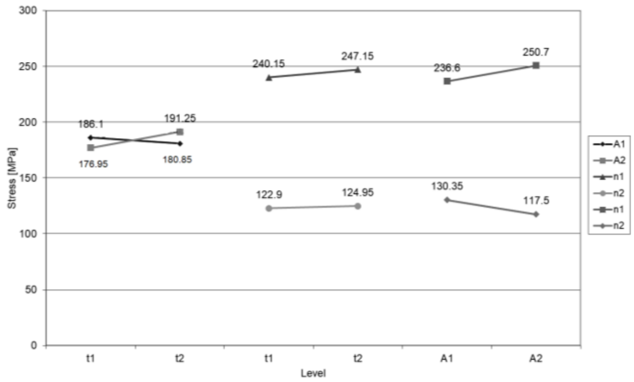

Fig. 11. The graphic representation of the interactions about value of the equivalent tension

5. CONCLUSIONS

The results, although they have a realistic expression, cannot be close to the experimental ones, due to the differences existing between the real and the modeled system.
Respecting the level of critical stress and thus, the passage of the material in the plastic field, allows establishing the maximum areas of demand of the diaphragm during operation.
The purpose of the present analysis is to obtain a description of the distribution of specific stresses and

deformations, which will be a model for the experimental approach.

Considering the above representations it can be stated that, for the radial diaphragms, the deformations are maximal in its center.

It is observed that the equivalent stress reaches higher values in the case of the radial diaphragm, at the end of the corrugation from the embedding area regardless of the value of the corrugated amplitude. There is also a decrease of the equivalent stress in the case of the radial diaphragm as the amplitude and the number of corrugations increase. Increasing the number of corrugations leads to increased diaphragm stiffness.

The possibility of experimentally establishing the state of stresses and deformations that appears in the material of the corrugated diaphragm at its request with a uniformly distributed pressure is reduced, therefore it was considered necessary to use an easy-to-apply numerical method but which has the disadvantage of obtaining the results based on some simplifying hypotheses.

Use of M.E.F. it proves to be useful in optimizing the geometry of diaphragms, because it facilitates the analysis of their behavior, considering that from a technological point of view it is difficult to approach a study that would allow the possibility of improving their performances by modifying the constructive parameters.

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