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RESEARCHES REGARDING THE RELATION FORCES – DEFORMATIONS ON EXTENSIBLE ELASTIC DIAPHRAGM CHUCK WITH JAWS

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ABSTRACT

The paper presents an analysis, of plane stress and deformation, of elastic diaphragms that are used on elastic diaphragm chuck with jaws.
A comparison, of induced stress and deformations, study was made by using the relations from different sources. In consideration of relations that describe induced stress and deformation on plan, circular, embedded, plate, loaded with a concentrated force and current knowledge regarding jaws, elastic, membrane, mechanisms. For the verification of the results obtained, was used the Finite Element Method.
The result obtained by using the finite element analysis, led on the conclusion that, the values for maximum stress calculated by using the mathematical model for Fixtures are closer than the results obtained form model

KEYWORDS: fixtures, elastic diaphragm with jaws, stress, deformation.

1. THE OBJECTIVE OF THE PAPER

The objective of the paper is the determination of maximum stress and deformation that is emerging in the interior of the diaphragm, from the structure of elastic diaphragm chuck with jaws, results of elastic deformations during the centering and gripping under the action of the acting force.

2. GENERAL CONSIDERATIONS ON EXTENSIBLE ELASTIC DIAPHRAGM CHUCK WITH JAWS

Fixtures can be defined as auxiliary components of technological systems, having the role of orienting and positioning of parts, tools, gauges, etc., in accordance with the requirements of cutting, inspection, assembly etc, and to maintain (preserve) this orientation in time [2], [9], [10].

Fixtures used in machinery construction can be defined as auxiliary components (elements, links) of the technological systems, having the functions, (role, purpose, destination), of orienting and positioning of parts (semi – finished articles, assemblies, cutting tools, gauges), in accordance with the requirements of cutting, inspection,assembly, and to fix it in order to maintain (preserve, conserve) this specific position, used in machinery construction [2], [9], [10].

Extensible elastic diaphragm devices for positioning and fixing are characterized by the existence, in the construction, of an elastic diaphragm, in which are embedded a series of jaws, radial disposed. The jaws can effectuate the centering on short interior surfaces (bolts, rods), or short exterior surfaces (chucks). The centering and fixing is done by the elastic deformation of the diaphragm. The material and heat treatment used is the as in the case of springs.

Fixtures, which contain this type of devices, are used for centering machined parts with tight tolerance, on finishing operation, where the stress is low. It has a simple construction and can be operated manually or mechanized. Correctly manufactures and exploited, precision of 0.01 mm can be achieved [4].

Fixing forces *S* are realized in the absence of the acting force *Q*, due to the remanent stress inside the diaphragm. In the case of the adjustable chucks, screws allow the adjustment of the device for various diameters of the clamping surfaces and also allow the remodel of the centering precision by grinding, in case of wear.

Compared to the centering and fixing mechanisms with radial sliding jaws movedthrough a channel provided with disk-shaped Arhimede spiral (universal three jaws chucks), the elastic diaphragm chuck presents a number of advantages, namely: centering and fixing accuracy, because of the higher numbers of centering elements, reduced times for clamping (centering and fixing) and detaching (removal and weakening) of the parts, constructive simplicity, easy to mechanize, easy and convenient service [3].

Disadvantages, of the elastic diaphragm chucks, compared to the universal three jaws chucks are: the need for previous adjustments of the centering and clamping elements, the possibility of appearance of plastic strains of the membrane, the construction of centering and clamping elements with screws, determines the amendment of the initial adjustments because o the game thread (which is increasing as use) [14].

3. WORK METHODOLOGY

For the achievement of the objective the next methodology was used:

- Identification of bibliographical sources form *Material strength* and *Fixtures* domain and connected domains.
- Identification and analyze of stress calculus relation from *Material strength* regarding induced stress and deformation of plan, circular plane.
- Identification and analyze of calculus relation from Fixtures bibliography.
- Identification and analyze of calculus modalities regarding stress and deformation of elastic diaphragm using finite element analysis.
- Comparative analysis, for a certain variant of mechanism of centering and gripping, of induced stress and deformation by using calculus relation from *Material strength*, *Fixtures*, finite element method.
- Formulating the conclusions.

4. CONDITIONS FOR RESEARCH

A diaphragm with adjustable (Fig. 1.) jaws was investigated with the following parameter, from the endowment, of Fixtures laboratory from The "Gheorghe Asachi" Technical University of Iasi:

$r_f = 30$ mm;
$r_m = 95$ mm;
$r_t = 16$ mm;
$a = 22{,}5$ mm;
$g = 5{,}5$ mm;
$n_f = 12$;
$d_p = 2r_p = 30$ mm;
$T_{dp} = 0{,}02$ mm;
$J_{f\min} = 0{,}02$ mm.

It was considered a force for fixing the part S = 100 daN.

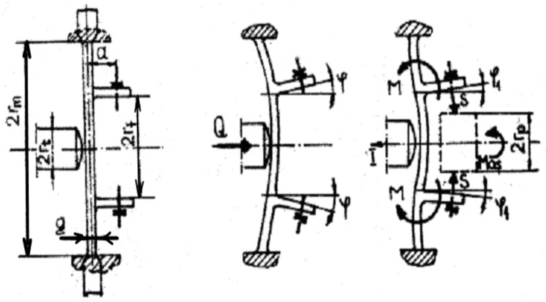

Fig. 1. The operating principle of elastic diaphragm devices for positioning and fixing with jaws [19]

5. DETERMINATION OF THE DEFORMATION AND STRESS IN ELASTIC DIAPHRAGM BASED ON KNOWN CALCULATION RELATION

5.1. Relation between forces and deformations

5.1.1.Mathematical models for determining the strains and tensions from the literature of Material resistance

Mathematical model for determining the strains and stresses that occur during deformation of elastic membranes, because the driving force, is described in the literature of *Fixture*. The source of these relations is the literature for *Material resistance*. From the Resistance of materials *Material resistance* point of view, elastic membranes are considered *plane, circular, thin, embedded plates*, on which concentrated forces are applied through acting rods [1].

Plates, unlike bars, have two dimensions – length and width – relatively high compared with the third – thickness. Many components of machines or buildings have elements in the form of plates, flat or curved, pistons, cylinders, tanks of various shapes, valves, pipes, floor, roof, etc. of various types [14].

The study of plates is more complicated than the bars and it is done in the *Theory of elasticity*. Geometric elements that characterize a plate are: the shape and size of the median area and the width, measured perpendicular to the median surface. The median surface divides the plate in to two equal parts, in any section. After the area of median section plates are divided into two major groups: flat plates and curved plates or coverings [14].

In terms of mechanics, the plates resist any efforts. Very thin plates, which cannot only retrieve stretching efforts, wear the name of *diaphragms*. Following the deformation of the plate, the median area, takes o curve shape. The deformation ω of the plate, compared to the initial median plane, is considered small compared to plate thickness [1].

After the median area, flat plates can be circular, rectangular, elliptical or other shapes. Plates which symmetry can be lean and loaded symmetrically which simplifies much the calculations.

Equations of strains for the maximum deformation in the membrane ω, and angle of the jaw opening of φ are [1, 14]:

$$\omega = \frac{Q r_m^2}{8\pi D}\ln\frac{r_f}{r_m} + \frac{Q}{16\pi D}\left(r_m^2 - r_f^2\right) \text{ [mm];} \quad (1)$$

$$\varphi = \frac{Q r_m}{8\pi D} 2\ln\frac{r_m}{r_f} = -\frac{Qr}{4\pi D}\ln\frac{r_m}{r_f} \text{ [rad],} \quad (2)$$

where the acting force Q results:

$$Q = -\frac{4\pi D\varphi}{r_f \ln\frac{r_f}{r_m}} \text{ [daN],} \quad (3)$$

where:

Q – the force necessary for acting the diaphragm daN;

r_f – radius of the circle layout of jaws, mm;

r_m – membrane radius, measured from its center to the restraint point, mm;

φ – angle of the jaw opening, rad, which can be determined by the relationship:

$$\varphi = \varphi_1 + \varphi_2 + \varphi_3 \text{ [rad],} \quad (4)$$

where:

φ_1 – angle that ensures the achievement of the necessary fixing force due to elastic deformation membrane:

$$\varphi_1 = \frac{M r_f}{D(1+\mu)} \text{ [rad],} \quad (5)$$

where:

M – specific moment evenly distributed daNmm/mm;

μ – Poisson's coefficient for the membrane material 0.25 … 0.35;

D – cylindrical membrane rigidity, which can be determined by the relationship:

$$D = \frac{E g^3}{12(1+\mu^2)} \text{ [daN/mm}^2\text{],} \quad (6)$$

where:

E – modulus of elasticity, normal of material diaphragm daN/mm ^{2};

φ_2 – additional angle of the jaws opening, which takes into account the tolerances δ of the part in diameter, which can be determined by the relationship:

$$\varphi_2 = \frac{T_{dp}}{2a} \text{ [rad].} \quad (7)$$

φ_3 – additional angle of the jaws opening which takes into account the diametral plays $J_{f\min}$, necessary for the free introduction and removal of the part, which can be determined by the relationship:

$$\varphi_3 = \frac{J_{f\min}}{2a} \text{ [rad],} \quad (8)$$

where a – length of the jaws.

Maximum stress inside the diaphragm is determined by the following relationship:

$$\sigma_{\max} = -\frac{Q(1+\mu)}{g^2}(0.485 \cdot \ln\frac{r_m}{r_f} + 0.52) \text{ [daN/mm}^2\text{],} \quad (9)$$

where g – thickness of membrane, mm.

Maximum displacement inside the diaphragm is determined by the following relationship:

$$\omega_{\max} = \frac{Q r_m^2}{16\pi D} \text{ [mm].} \quad (10)$$

5.1.2. Mathematical model for determining the strains and tensions in the literature of Fixtures

Specific relationships from Fixtures literature consider the acting force for the diaphragm deformation from the elastic diaphragm chuck the clamping force developed by the elastic diaphragm.

The acting force Q necessary to open the jaws on elastic extensible diaphragm devices for positing and fixing the part can be determined by the relationship [3, 12, 19]:

$$Q = -\frac{4\pi D\varphi_1}{3 r_f \ln\frac{r_f}{r_m}} \text{ [daN].} \quad (11)$$

The equation for determining the angle that ensures the achievement of the necessary fixing force due to elastic deformation membrane, is:

$$\varphi_1 = \frac{C M r_s}{D(1+\mu)} = \frac{C S a r_f}{2\pi D(1+\mu)} \text{ [rad];} \quad (12)$$

where C – coefficient of proportionality depending of the ratio r_m / r_s presented in table 1.

The equation for maximum stress determined by the action of the acting force given the previous notation, is:

$$\sigma_{\max} = \frac{3Q(1+\mu)}{2\pi g^2}(\ln\frac{r_m}{r_f} + \frac{r_f^2}{4 r_m^2}) \text{ [daN/mm].} \quad (13)$$

Table 1. Coefficient of proportionality depending on the r_m / r_s [19]

$\frac{r_m}{r_f}$	1,25	1,5	1,75	2
C	0,822	0,675	0,590	0,560
$\frac{r_m}{r_f}$	2,25	2,5	2,75	3
C	0,555	0,565	0,575	0,585

Maximum displacement is determined by the following relationship:

$$\omega_{\max} = atg\varphi \text{ [mm].} \tag{14}$$

The analysis of knowledge and in particular the relations for available bibliographical sources, form *Material resistance* and *Fixtures* led on the conclusion that there are a series of differences between the mathematical model for determination of forces, deformations and stress, differences, namely the introduction of additional factor 1/3, in the formula for calculating the acting force *Q*.

Regarding the formula for calculating the angle of the jaw opening φ_1 presented in literature for Devices, it contains an additional coefficient of proportionality *C*. These coefficients take into account the shape of the elastic membranes with jaws from the structure of extensible, centering and fixing mechanisms, that substantially differs to flat plates treated in the literature of Material resistance

Calculation formulas for determining maximum stress are completely different.

5.1.3. Analysis of deformation and tensions using finite elements method

Finite elements method (FEM – Finite Element Method) is one of the best existing methods for achieving the various calculations and simulations in engineering. This method, and, of course, programs that incorporate it, became a basic component of modern computer-aided design [11].

In general, engineering, and particularly in the construction of machinery, equipment and installations, the basic component of a system, the resistance structure, is analysed by FEM, defined as a group having a mechanical function very clearly established, such as taking of load, providing a certain functionality or movements between some sub-assemblies, ensuring static/ dynamic stability and guaranteed rigidity imposed by the designer, etc.

It should be noted that in the sequence: CAD – FEM – CAM exists an iterative process of design – calculation – performance in this process is carried out successively, operations summary and analysis of prototype and model for finite element calculation. At each iteration, of the process, improvements are made to the prototype or model of computation, to achieve desired performance. Finite element analysis of a model structure is in fact, numerical calculation verification [11].

Thus, for a given defined dimensional geometry for a given loading and support conditions well specified (restrictions), the results obtained are strains, tensions, reactions in supports and frequencies.

A comparison for the calculated values of stress and deformation was made using, the finite element analysis module Cosmos Works from Solid Works 2007 computer aid design software. In the first step, the diaphragm was the modelled and the appropriate material was selected. To implement the finite element analysis, restrictions were applied on the outlines of the membrane and a deformation force applied in the center membrane. By applying deformation forces, were calculated the maximum stress and maximum travel of the membrane.

5.2. Calculation of the acting forces, stresses and displacement

Given the mathematical model presented form literature of *Material resistance* and *Fixtures*, the values for the forces, tensions, and displacement were determined, as shown in table 2.

In Fig. 2 and Fig. 3 are presented maximum displacement on elastic diaphragm with jaws, maximum stress and stress distribution on elastic diaphragm with jaws, determined with finite element analysis.

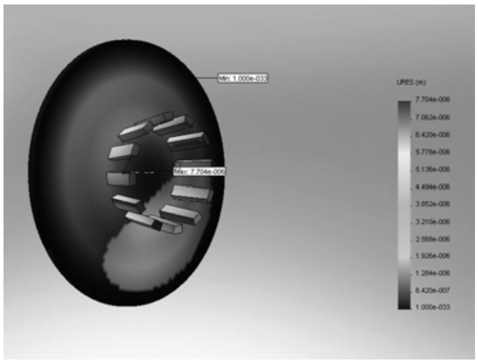

Fig. 2. Maximum displacement on elastic diaphragm with jaws

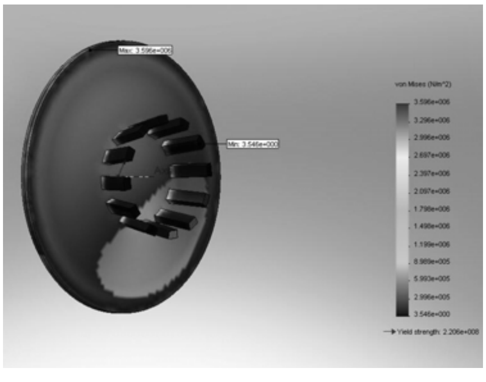

Fig. 3. Maximum stress and stress distribution on elastic diaphragm with jaws

Table 2. Calculated value for acting force, stress, displacement

Parameter	According to the literature Material resistance [1, 14]		According to the literature of Fixtures [3, 12, 19]	
	Relations	Values	Relations	Value
Angle of jaw opening φ_1 [rad]	$\varphi_1 = \frac{Mr_f}{D(1+\mu)} = \frac{Sar_f}{2\pi D(1+\mu)}$	0,00086	$\varphi_1 = \frac{CMr_f}{D(1+\mu)} = \frac{CSarf}{2\pi D(1+\mu)}$	0,0005
Additional angle of the jaws opening, which takes into account the tolerances T_{dp} of the part, φ_2 [rad]	$\varphi_2 = \frac{T_{dp}}{2a}$	0.00044	$\varphi_2 = \frac{T_{dp}}{2a}$	0.00044
Additional angle of the jaws opening which takes into account the diametral plays, φ_3 [rad]	$\varphi_3 = \frac{J_{f\min}}{2a}$	0.00044	$\varphi_3 = \frac{J_{f\min}}{2a}$	0.00044
Angle of jaw opening φ [rad]	$\varphi = \varphi_1 + \varphi_2 + \varphi_3$	0,00174	$\varphi = \varphi_1 + \varphi_2 + \varphi_3$	0,00139
Acting force Q [daN]	$Q = -\frac{4\pi D\varphi}{r_f \ln \frac{r_f}{r_m}}$	203,75	$Q = -\frac{4\pi D\varphi}{3r_f \ln \frac{r_f}{r_m}}$	53,97
Maximum stress σ_{max} [daN/mm^2]	$\sigma_{\max} = -\frac{Q(1+\mu)}{g^2}(0.485 \cdot \ln \frac{r_m}{r_f} + 0.52)$	9,41	$\sigma_{\max} = \frac{3Q(1+\mu)}{2\pi g^2}(\ln \frac{r_m}{r_f} + \frac{r_f^2}{4r_m^2})$	1,96
Maximum displacement ω_{max} [mm]	$\omega_{\max} = \frac{Qr_m^2}{16\pi D}$	0,11	$\omega_{\max} = a \cdot tg\varphi$	0,031
Values determined using the method of finite elements				
Maximum stress [daN/mm^2]	The value of maximum stress determined by applying a force of 203.75 [daN]	1,3	The value of maximum stress determined by applying a force of 53.97 [daN]	0,359
Maximum displacement [mm]	The value of maximum displacement determined by applying a force of 203.75 [daN]	0,0028	The value of maximum displacement determined by applying a force of 53.97 [daN]	0,00077

The value calculated using mathematical model from Fixture literature for opening angle of the jaw are lower than values calculated by using mathematical model from Material resistance because of the presence of a coefficient of proportionality *C*.

The values for the acting force calculated by using the formula from Fixtures, is lower by 3,7 times than the value calculated by using the formula from Material resistance, because of the additional factor.

Regarding the maximum stress value σ_{max} calculated according to the Fixtures literature, is 4,8 times less than the maximum stress value calculated with the model from the literature of Material resistance, due to different values in terms of the acting force and the difference on the structure of the formulas.

The value for the maximum displacement calculated using the mathematical model from Material resistance is 7,2 time greater than the value determined by finite element analysis, the value for displacement calculated using the mathematical model from Material resistance is 39,2 times greater, than the value determined by finite element analysis.

The value for the maximum displacement calculated using the mathematical model from Fixtures is 5,4 time greater than the value determined by finite element analysis, the value for displacement calculated using the mathematical model from Fixtures is 40 times greater than the value determined by finite element analysis.

6. CONCLUSIONS

The mathematical model for determining the force, stress and displacement presented in *Fixtures* literature is adjusted by introducing correction factors for reducing the degree of generality of these formulas, this results in reduced values for displacement and stress, so constructive particularities of the diaphragm are taken into account.

Literature for Fixtures does not present the reasoning of introducing these additional coefficients in these formulas.

The result obtained by using the finite element analysis, led on the conclusion that, the values for maximum stress calculated by using the mathematical model presented Fixtures literature are closer than the results obtained form model described in Material resistance literature.

The experiment is the only one that can show with certainty which of the models is closest to reality and the only one that can validate the presented results.

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