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Classification of Micromechanical Elements and Fabrication of Beam-type Micromechanical Elements

Desislava Petrova
Department "Management"
Technical university of Gabrovo
Gabrovo, Bulgaria
des_petrova@abv.bg

***Abstract*—This article presents the developed classification of micromechanical elements, as well as the calculations and fabrication of micromechanical elements of the beam type, using the theory of elasticity and the Finite Element Method (FEM). The principle of etching a conventional angle and partial etching of freely vibrating components is considered. The technical model of the clamped beam, physical and mathematical modeling, as well as simulation and verification of correctness are described. The relationship between the design and entry into the database of the automated design system "MICROSYS 25" of microsystem engineering products is presented.**

Keywords— classification of micromechanical elements (MMEs), design, modeling.

I. Introduction

Digital skills and competences have an important role in increasing the possibilities of adaptation of human capital to the changing requirements of jobs and the labor market in the conditions of Industry 4.0. [1 - 3].

The creation of any Microtechnology product (micromechanical component - MMC, Micromechanical element - MME, microcomponents - MC, sensors, etc.) is reduced to the construction of two systems of connections, relating to: the design of the Microsystems Technology product itself and the production process of its manufacture [4 - 7].

It is necessary that the connections in the production process (PP) be constructed in strict accordance with the system of connections contained in the design of the product itself, i.e. the technological process (TP) inherits the system of sets of the two types of connections characteristic of the design - a system of connections in the design of the product and that in the production process of the product, which is presented in Fig. 1.

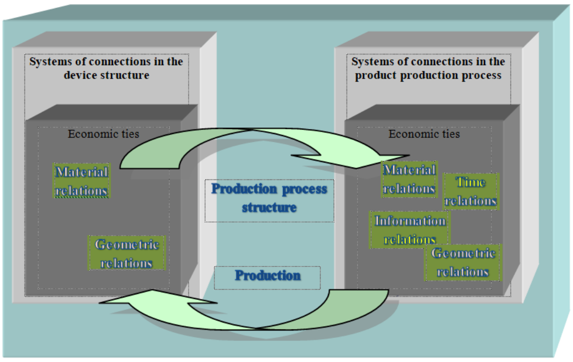

Fig. 1. General system of the sets of connections of the product design (MMK) and the production process [3 -6]

The system of connections that make up the product (MMC) can be considered strictly deterministic, while the production process is a very complex probabilistic system, belonging to the category of cybernetic control systems [8].

Considering the production process of making the product (MMC) as a manifestation of the overall system of sets, technology and studies these connections in order to solve the problem of ensuring the required quality at a given productivity and minimal expenditure of time, labor, energy and materials.

A microsystem can be defined as any element, device or system built from a certain number of Microcomponents (MCs). A generally accepted model of a microsystem is the model of a standard control system, shown in chapter one, Fig. 2. (generally accepted model of a microsystem). Most of the developed microsystems have this structure and can be constructed from components manufactured using different technologies on different substrates, but connected together in the form of

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a hybrid microsystem. Another possibility is for all components of the system to be manufactured on a common substrate, using an appropriate technology in the form of a monolithic (integrated) microsystem [9 - 12].

Each microsystem consists of one or more components from the three classes shown in fig. 2:

- Microsensors – detect changes in the system's environment;
- Intelligent components – make decisions based on changes determined by the sensors [13];
- Executive micromechanisms (actuators) – through them the system changes the parameters of the environment.

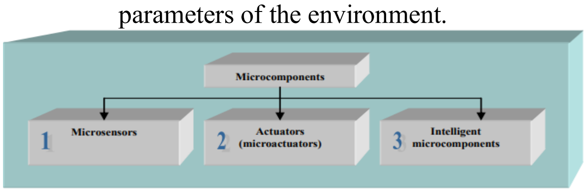

Fig. 2. Classification of Microcomponents (MCs)

The object of classification is two of the classes of microcomponents: microsensors and actuators, as well as MME included in their construction.

In the practice of AP, there are two methods for classifying design objects [14 - 16]:

- Hierarchical - the specified set of objects is divided into subordinate sets.
- Faceted - the specified set of objects is divided into independent sets for different classification features.

In the automated system for the design of MMEs and products from the MST "MICROSIS 25" the faceted method of classification is used. The choice is based on the fact that the classifiers developed in this way have the ability to be constantly supplemented with new elements and this does not violate their structure.

The purpose of the article is:

- To present the developed classification of micromechanical elements, as well as the calculations and fabrication of micromechanical elements of the beam type, using the theory of elasticity and the Finite Element Method (FEM) [17 - 19];
- To consider the principle of etching a conventional angle and partial etching of freely vibrating components [20];
- To describe the technical model of the clamped beam, the physical and mathematical modeling, as well as the simulation and verification of correctness.

II. Materials and Methods

Classification of microcomponents (MCs) – systematization and presentation in tabular form for more convenient work

Sensor – an element or device for converting a physical, chemical or biological measured quantity "m" into an equivalent signal "s", most often electrical, and this signal is a function of the measured quantity:

$$s = f(m) \qquad (1)$$

The executive mechanism (actuator) is an element that converts the electrical quantity into a physical, chemical or biological quantity [21].

This dependence represents a conversion characteristic and is a generalized theoretical form of the specific physical laws that govern the operation of individual sensors. The main parameter of the sensors is their differential sensitivity "S", which is defined as the ratio between the change in the output and the change in the input quantity:

$$s = \frac{ds}{dm} \qquad (2)$$

The classification of microsensors (MSs) is based on the following main classification features:

- According to the nature of the received output signal: Active sensors and Passive sensors.
- According to the position relative to the sensed object: Non-contact sensors and Contact sensors.

Non-contact sensors are divided according to the type of signal from the sensed element into: Electromechanical and Electromagnetic.

Contact sensors are divided according to:

- Type of impact Responsive: to touch; to sliding; to effort.
- The method of converting the applied force to the sensor into: Perceiving the force as a mechanical displacement of the sensor; and Perceiving the force as a deformation of the sensitive element.

The classification of executive micromechanisms is based on the following groups:

- Microactuators – divided into: Electrostatic; Magnetic; Multiplying and reducing; Piezoelectric; Magnetostrictive;
- Positioning and locating: Positioning; Gripping; Fastening.
- Microoptical: Microscanners; Microspectrome-ters.
- Thermal;
- Hydraulic and pneumatic;

- Biomedical: Micromanipulators; Microstimula-tors; Surgical microinstruments.

MMEs are listed as basic structures for microcomponents in Table 1. The emphasis is on the most common elements as basic structures in sensors, actuators and microsystems. The MMEs listed in the table are embedded in the developed classification.

TABLE 1 MMES AS BASIC STRUCTURES FOR MC

Micromechanical Elements (MMEs)	**Microcomponents (MCs)**
	Measurement of mechanical quantities:
Membranes, Plates	Force, torque, speed – acceleration sensors
Beams	Measuring heads for atomic force microscopy
Pyramid combs, V-shaped combs	-
Protruding structures, micro masses	Functions for propulsion and transmission, respectively control of energy flows
Micro nozzles, fluid channels	Microvalves, pumps
3D, partially movable structures	Inkjet printer heads
Linear and multidimensional displacement units	Electromechanical transducers (piezoelements, actuators for digital devices and video cameras)
Spring convex systems	Thermomechanical converters (bimetallic), micromotors, microgears
Gears	Moments broadcast
Needle supports	A set of them in a pressure sensor, raster probes for measuring temperature, the meaning of carrying a moment

The classification of MME has been developed and is divided into four levels of hierarchy:

- First level – type of MME;
- Second level – main characteristics of MME;
- Third level – method of attachment of MME;
- Fourth level – geometry of MME.

Fabrication of micromechanical beam-type elements

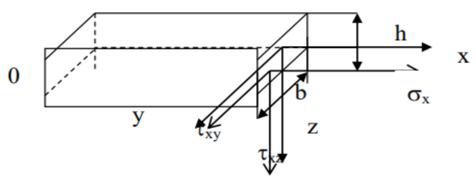

Fig. 3. Stresses expressing external forces on a beam

For their description, the theory of elasticity and FEM are used, which is particularly suitable for application in computer methods for calculation and simulation. A microcomponent of the beam type, located in the coordinate system x, y, z, is shown schematically in Figure 3.

After matching the geometry equations with the imposed constraints, they take the form:

$$\left| \begin{array}{l} \varepsilon_x = \frac{\partial u}{\partial x}; \gamma_{xy} = \frac{\partial u}{\partial y} + \frac{\partial v}{\partial x} \\ \varepsilon_y = \frac{\partial v}{\partial y}; y_{yz} = \frac{\partial v}{\partial z} + \frac{\partial w}{\partial y} = 0 \\ \varepsilon_z = \frac{\partial w}{\partial z} = 0; y_{zx} = \frac{\partial w}{\partial x} + \frac{\partial u}{\partial z} = 0 \end{array} \right. \tag{3}$$

Since the linear strain ε_z is equal to zero, it follows that the normal stress σ_z and the directional cone μ_z are also equal to zero. From this it follows that $\mu_x = \mu_y = \mu$.

The functional dependence between the individual quantities takes the form:

$$\left| \begin{array}{l} \varepsilon_x = \frac{1}{E}(\sigma_x - \mu\sigma_y) \\ \varepsilon_y = \frac{1}{E}(\sigma_y - \mu\sigma_x) \\ \gamma_{xy} = \frac{2(1+\mu)}{E}\tau_{xy} \end{array} \right. \tag{4}$$

The same relationship, but resolved in terms of voltages, is:

$$\left| \begin{array}{l} \sigma_b = \frac{E}{1-\mu}(\varepsilon_b + \mu\varepsilon_b) \\ \sigma_b = \frac{E}{1-\mu^2}(\varepsilon_b + \mu\varepsilon_b) \\ \tau_{bb} = \frac{E}{2(1+\mu)}\gamma_{bb} \end{array} \right. \tag{5}$$

After integrating we obtain:

$$\left| \begin{array}{l} v(x,y,z) = -z\frac{\partial w(x,y)}{\partial y} + v_0(x,y) \\ u(x,y,z) = -z\frac{\partial w(x,y)}{\partial x} + u_0(x,y) \end{array} \right. \tag{6}$$

Since $u_0(x,y)$ and $v_0(x,y)$ are unknown integration functions that are determined by the condition for non-deformability of the midline, then:

$$\left| \begin{array}{l} u(x,y,0) = 0 \\ v(x,y,0) = 0 \end{array} \right. \tag{7}$$

Substituting z = 0 into the system, we get:

$$\left| \begin{array}{l} u_0(x,y) = 0 \\ v_0(x,y) = 0 \end{array} \right. \tag{8}$$

Finally for the system we get:

$$\left| \begin{array}{l} u(x,y,z) = -z\frac{\partial w(x,y)}{\partial x} \\ v(x,y,z) = -z\frac{\partial w(x,y)}{\partial y} \end{array} \right. \tag{9}$$

After substitution we get:

$$\begin{vmatrix} \varepsilon_x = -z\frac{\partial^2 w}{\partial x^2} \\ \varepsilon_y = -z\frac{\partial^2 w}{\partial y^2} \\ \gamma_{xy} = -2z\frac{\partial^2 w}{\partial x \partial y} \end{vmatrix} \quad (10)$$

Substituting the deformations into the physics equations for the principal stresses, we obtain:

$$\begin{vmatrix} \sigma_x = -\frac{E_z}{1-\mu^2}\left(\frac{\partial^2 w}{\partial x^2} + \mu\frac{\partial^2 w}{\partial y^2}\right) \\ \sigma_y = -\frac{E}{1-\mu^2}\left(\frac{\partial^2 w}{\partial y^2} + \mu\frac{\partial^2 w}{\partial x^2}\right) \\ \gamma_{xy} = -\frac{E_z(1-\mu)}{(1-\mu^2)}.\frac{\partial^2 w}{\partial x \partial y} \end{vmatrix} \quad (11)$$

So far, we have obtained formulas for the principal stresses. It is necessary to obtain the secondary stresses using the same function w(x,y). The equations from statics are used:

$$\begin{vmatrix} \frac{\partial \tau_{zx}}{\partial z} = -\left(\frac{\partial \sigma_x}{\partial x} + \frac{\partial \tau_{yx}}{\partial y}\right) \\ \frac{\partial \tau_{zy}}{\partial z} = -\left(\frac{\partial \tau_{xy}}{\partial x} + \frac{\partial \sigma_y}{\partial y}\right) \\ \frac{\partial \sigma_z}{\partial z} = -\left(\frac{\partial \tau_{xz}}{\partial x} + \frac{\partial \tau_{yz}}{\partial y}\right) \end{vmatrix} \quad (12)$$

Substituting the expressions for σ_x, σ_y and $\tau_{xy} = \tau_{yz}$, performing the indicated differentiation operations and integrating once with respect to the parameter z, we obtain:

$$\begin{vmatrix} \tau_{zx} = \tau_{xz} = \frac{Ez^2}{2(1-\mu^2)}.\frac{\partial}{\partial x}\nabla^2 w + f_1(x,y) \\ \tau_{zy} = \tau_{yz} = \frac{Ez^2}{2(1-\mu^2)}.\frac{\partial}{\partial y}\nabla^2 w + f_2(x,y) \end{vmatrix} \quad (13)$$

where $f_1(x,y)$, $f_2(x,y)$ are the unknown integration functions, and ∇ is the Laplace operator.

$$\nabla^2 = \frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} \quad (14)$$

The determination of the integration functions is carried out from the boundary conditions, or at z = +h/2 , $\tau_{zx} = 0$, $\tau_{zy} = 0$.

$$\begin{vmatrix} f_1(x,y) = -\frac{Eh^2}{8(1-\mu^2)}.\frac{\partial}{\partial x}\nabla^2 w \\ f_2(x,y) = -\frac{Eh^2}{8(1-\mu^2)}.\frac{\partial}{\partial y}\nabla^2 w \end{vmatrix} \quad (15)$$

From here for the stiffness we get:

$$F = \frac{Eh^3}{12(1-\mu^2)} \quad (16)$$

Determination of bending moment:

$$M_y dy = \int_{-\frac{h}{2}}^{+\frac{h}{2}} z\sigma_x dy dz = dy\int_{-\frac{h}{2}}^{+\frac{h}{2}} z\sigma_x dz \quad (17)$$

According to the analogue principle, it can be used and used for other purposes. It finally works:

$$\begin{vmatrix} M_y = -F\left(\frac{\partial^2 w}{\partial x^2} + \mu\frac{\partial^2 w}{\partial y^2}\right) \\ M_x = -F\left(\frac{\partial^2 w}{\partial y^2} + \mu\frac{\partial^2 w}{\partial x^2}\right) \\ M_{xy} = M_{yx} = -F(1-\mu)\frac{\partial^2 w}{\partial x \partial y} \end{vmatrix} \quad (18)$$

The stresses as a function of internal forces are:

$$\begin{vmatrix} \sigma_x = \frac{M_y}{J}z \\ \sigma_y = \frac{M_x}{J}z \\ \tau_{xy} = \frac{M_{xy}}{J}z \end{vmatrix} \quad (19)$$

where the moment of inertia is $J = \frac{h^3}{12}$

Strength verification is performed using the IVth strength theory.

$$\sigma_{equivalent}^{IV} = \sqrt{\sigma_1^2 + \sigma_2^2 - \sigma_1\sigma_2} \quad (20)$$

Clamped beams, bent beams or freely suspended elements made of resistive insulating layers (SiC, Si_3N_4, SiO_2) or silicon are suitable as basic structures for acceleration sensors, resonators or thermal insulation of functional elements. They are produced from silicon wafers by etching at conventional angles.

Figure 4 shows a structured resistive layer of Si3N4 (silicon nitride) on a U-shaped cutout for obtaining an MME beam type. Its edges are parallel to the intersection lines of the (111)-plane. Anisotropically acting solutions remove material perpendicular to the surface layer in the (100)-plane direction. The etching process is carried out by removing in the (411)-plane direction.

The etching rates of silicon planes with larger etching coefficients are highly dependent on the production conditions (temperature, concentration, presence of cations, addition of alcohol, stirring of the solution, etc.).

The etching time t is obtained by assuming the condition that for the complete release of a beam-type element in the (411)-front direction starting from the conventional angles at which the base x (Fig. 3.) lies opposite:

$$t = \frac{x}{\ddot{A}R_{(411)}} = \frac{x}{[u.\ddot{A}R_{(100)}]} \quad (21)$$

where: ÄR(411) is the etching rate in the (411)-plane direction; ÄR(100) is the etching rate in the (100)-plane direction.

Then the etching depth (d) is:

$$d = t.\ddot{A}R_{(100)} \quad (22)$$

Silicon beam structures can be fabricated using stop layers using the following methods: bromine doping by ion implantation, epitaxy or diffusion, electrochemical or chemical etching.

The clamped beam is mainly subjected to bending. It is fabricated by etching at conventional angles. Silicon beam structures can be fabricated using stop layers – bromine doping, by ion implantation, epitaxy or diffusion, electrochemical or chemical etching [22, 23].

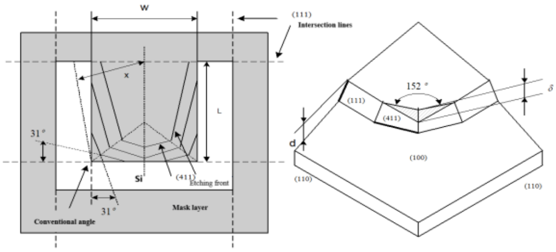

Fig. 4. Principle of conventional corner etching and partial etching of freely vibrating components

In the "Project" category on CAD system "MICROSYS 25" there is the goal setting, current status, statistical data, results.

In the "Development" category, there is the name and date of development, data on their properties and structure – geometric dimensions, material-specific characteristics or system characteristics [24].

In the "Technology" category, the technology for manufacturing MMC is described. For the current example with a clamped beam – by etching the conventional corners or with stop layers for Si structures – beam type, by doping with bromine, by ion implantation, epitaxy or diffusion, electrochemical or chemical etching [25].

In the "Production" category on CAD system "MICROSYS 25", there is the data on the production and quality assurance of the components – product name, serial number and date of production.

In the "Modeling" category on CAD system "MICROSYS 25"– description of the validity area, quality, modeling method – by theorist based on physical laws determined by studying the behavior of the system as a result of numerous measurements. The parameters used in modeling are replaced as characterizing data in the database (DB). Such are, for example: moment of inertia, spring constant, resonant frequency, damping coefficient, etc.

In the "Simulation" category are the results of the simulations performed, the simulation model used and the type of simulation.

III. Results and Discussion

Technical model (Fig. 5) – tensioned beam:

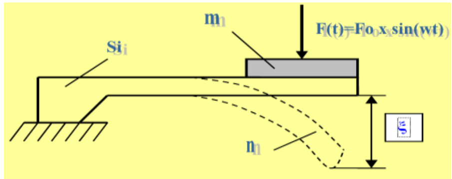

Fig. 5 Technical model of the tensioned beam ξ

Physical modeling – the tensioned beam is presented in Fig. 6.

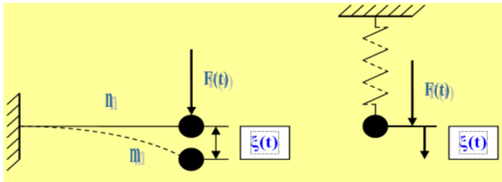

Fig. 6 Physical model of the tensioned beam

Mathematical modeling – represents an equivalent electrical circuit. Shown in Figure 7.

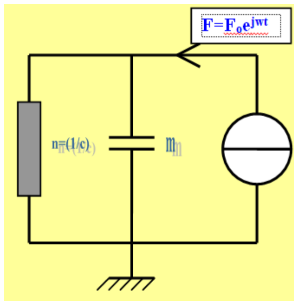

Fig. 7 Mathematical model of the tensioned beam

Simulation:

- Mathematical modeling solutions [26 - 28];

$$\mathrm{B}(w) = \frac{\zeta(w)}{F(w)} = n.\frac{1}{\left(1-\frac{w}{w_0}\right)}.w_0{}^2 = \frac{1}{(m.n)} \qquad (23)$$

- Analysis of the solution found and graphical interpretation – fig. 10.

Verification of correctness (proof) – Fig. 8 and Fig. 9.

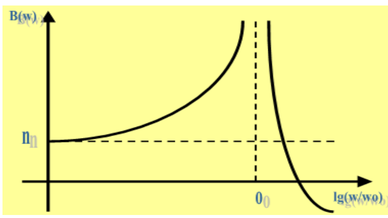

Fig. 8. Graphic of the solution of the tensioned beam model

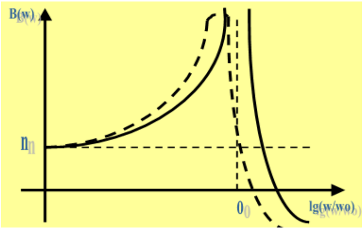

Fig. 9. Verification

The physical model is modified, which is then compiled from the corresponding mathematical model – Fig. 10.

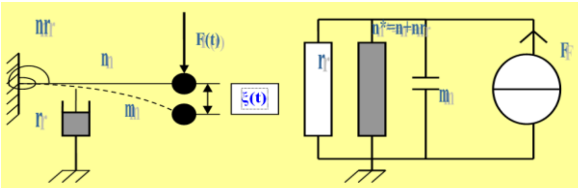

Fig. 10 Modified model of the tensioned beam model

Solution:

$$\mathrm{B}(w) = \frac{\zeta(w)}{F(w)} = n.\frac{1}{\left\{1+\left[j.\frac{1}{Q}.\frac{w}{{w_0}^{*2}}\right]-\left(\frac{w}{{w_0}^{*2}}\right)^2\right\}} \qquad (24)$$

$${w_0}^{*2} = \frac{1}{(m.n^*)}$$

$$Q = \frac{1}{{w_0}^{*2}.n.r}$$

Where:

B – magnetic induction;

m – mass;

F – force;

Q – resonant quality factor;

n – susceptibility;

r – frictional resistance;

j – imaginary part;

w – circular frequency;

w_o – resonant frequency;

ξ – displacement;

F_o – excitation force;

nr – torsional elasticity;

b – width;

z – resistance;

z_W – wave resistance;

W – step response;

t – time.

An example of a model of a beam loaded in bending (Fig. 11) can be represented by the following types of models:

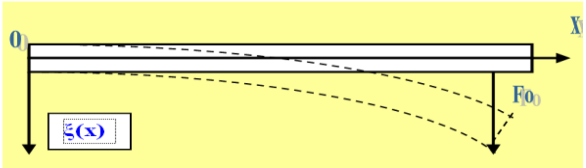

Fig. 11 Diagram of a beam under bending load

Differential equation of a beam under bending load:

$$\mathrm{EI}\xi(x)^{\mathrm{III}} = 0 \qquad (25)$$

$$\xi(0) = 0 \qquad (26)$$

$$\xi^{\mathrm{I}}(0) = 0 \qquad (27)$$

$$\xi^{\mathrm{II}}(0) = 0 \qquad (28)$$

$$-\mathrm{Ei}\xi^{\mathrm{III}} = 0 \qquad (29)$$

Where: E is the modulus of elasticity;

I – surface moment of inertia;

i – current;

ξ – displacement.

Mesh model of a beam loaded in bending (Fig. 12 and 13).

$$n = \frac{l^3}{12.E.I} \qquad (30)$$

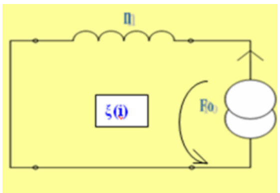

Fig. 12 Network model

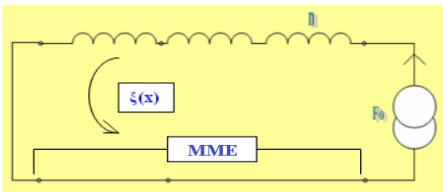

Fig. 13 Final network model

Finite element method – Fig. 14

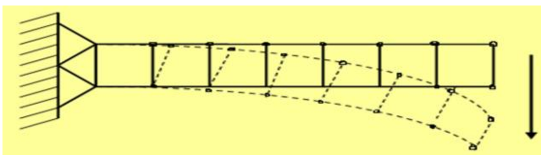

Fig. 14 End elements of a tensioned beam loaded in bending.

Thus, from a project to a final product, by sequentially going step by step through the categories in the CAD system "MICROSYS 25" database, taking into account the classification of microcomponents. The development of MMC consists of many technological methods, united in a certain technological sequence. The project needs relevant technologies, not technological dependencies.

The most common case in engineering practice is loading the beam in the xz plane with concentrated forces and moments or distributed forces with intensity $q(x)=q_z(x)$. In this case, the differential dependencies take the form [29]:

$$\frac{dQ}{dx} = -q(x) \tag{31}$$

$$\frac{dM}{dx} = Q(x) \tag{32}$$

Where $Q = Q_z$, $M = M_y$, $q = q_z$. In formulas for simplicity of writing, the indices of Q, M, and q are omitted, since there is no danger of making an error.

When differentiating the second dependence of with respect to x again, we obtain [30]:

$$\frac{d^2M}{dx} = \frac{dQ(x)}{dx} = -q(x) \tag{33}$$

$$M'' = -q(x) \tag{34}$$

The flow of the technology simulation is shown in Fig. 15.

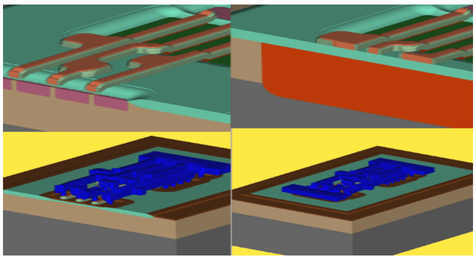

Fig. 15 Simulation of technology of a tensioned beam loaded in bending

The choice of the type of analysis and the geometry of the finite elements depend on the problem statement. When choosing 3D elements or 2D elements, the difference in the obtained result is minimal. In many cases, it is possible to reduce the dimensions without causing serious changes in the accuracy of the result. Many simulation tasks result in a symmetrical geometry. Then it is possible to present only a part of the detail, for example half or a quarter of it. This reduction of dimensions saves significant calculation time, so the deviation in the result can be ignored. In order to visualize the results of the simulation, a program called Post-Processor is used. With the help of this program, the result can be visualized both in numerical and graphical form. Another option when visualizing the results is the ability to animate the deformation. The program allows saving the results for the purpose of further processing and research.

IV. Conclusions

The developed classification of micromechanical elements is presented, as well as the calculations and fabrication of micromechanical elements of the beam type, using the theory of elasticity and the Finite Element Method (FEM);

The principle of etching a conventional angle and partial etching of freely oscillating components is considered;

The technical model of the clamped beam, physical and mathematical modeling, as well as simulation and verification of correctness are described.

An analysis-summary of the existing classifications of microcomponents is carried out: microsensors and executive micromecha-nisms (actuators), micromechanical elements and basic technologies in microtechnology, using known classification features.

References

[1] N. Kolev; Aleksandrova I, Metev H. Modeling and Optimiza-tion of Tool Life When Machining 42CrMo4+QT Steel on Swiss-Type CNC Lathes. In: 33rd International Scientific Symposium Metrology and Metrology Assurance, MMA 2023, Conference Proceedings, Sozopol 7-11 September 2023,Code 194604, DOI: 10.1109/MMA59144.2023.1031792, ISBN: 979-835033810-2.

[2] N. Nikolova, Development of a System for Assessment of Digital Professional Suitability in the Company Environment, Vide. Tehnologija. Resursi - Environment, Technology, Resources, Volume 3, Pages 211 – 216, 2024, 15th International Scientific and Practical Conference on Environment. Technology. Resources, ETR 2024, Rezekne, 27 June 2024 through 28 June 2024, Code 201245, Conference Proceedings, ISSN 16915402, ISBN 978-171389957-0, DOI 10.17770/etr2024vol3.8136.

[3] N. Nikolova, N., Human Capital in the Changing Work Environment of Industry 4.0, Vide. Tehnologija. Resursi - Environment, Technology, Resources, Open Access, Volume 3, Pages 187 – 193, 2023, 14th International Scientific and Practical Conference on Environment. Technology. Resources, ETR 2023, Rezekne, 15 June 2023 through 16 June 2023, Code 191610, DOI: https://doi.org/10.17770/etr2023vol3.7177

[4] D. Petrova., Doctor tezis, Database for automated design of micromechanical components for microsystems engineering products, Gabrovo, 2008

[5] D. Petrova, Intelligent, Innovative and Sustainable Industry in Bulgaria – prospects and challenges, Vide I. Tehnologija. Resursi - Environment, Technology, Resources, Proceeding of the 12th International Scientific and Practical Conference „Environment. Technology. Resources", June 20-22, 2019, Rezekne, Latvia, Volume I, pp. 210-215, ISSN 1691-5402 – print, ISSN 2256-070X – online. https://doi.org/10.17770/etr2019vol1.4188

[6] D. Petrova, An Alternative Approach to Reducing Aging of Innovative Industrial Products in Terms of Industry 4.0, Environment. Technology. Recourses – Proceeding of the 13-th International Scientific and Practical Conference, Rezekne Academy of Technologies, Rezekne, Latvia, 2021, ISSN 1691-5402, Online ISSN 2256-070X, https://doi.org/10.17770/etr2021vol3.6507 p. 274-280, scopus

[7] D. Petrova, Vlahova, B., Lengerov, A., Zlateva-Petkova, T., Study of the State of Innovation Development and Obsolescence in the Republic of Bulgaria of Companies from the Mechanical Engineering Sector, Vide. Tehnologija. Resursi - Environment,

Technology, Resources, 2023, 1, pp. 187–194, DOI: https://doi.org/10.17770/etr2023vol1.7239 , https://www.scopus.com/authid/detail.uri?authorId=56323816400

[8] I. Ahmad, T. Kumar, M. Liyanage, J. Okwuibe, M. Ylianttila and A. Gurtov, 'Overview of 5G Security Challenges and Solutions', IEEE Communications Standards Magazine, vol. 2, no. 1, pp. 36-43, March 2018.

[9] H. Metev, T. Kuzmanov, Manufacturing Technologies (part IV), Technological processes for CNC machines, „EX-PRESS“Ltd. – Gabrovo, Gabrovo, 2007.

[10] H. Metev, Krumov K. Determination of inaccuracy by milling taking into account the phenomenon of technological heredity. In: 9th International scientific conference "TechSys 2020" – Engineering, technologies and systems, Plovdiv, 2020. IOP Conf. Series: Materials Science and Engineering 2020; 878(1), 012049. doi:10.1088/1757-899X/878/1/012049.

[11] H. Metev, Krumov K, Vlahova B. Economic Aspects Of The Modular Tools. In: 11th International Scientific Conference “TechSys 2022” - Engineering, Technologies and Systems, Technical University of Sofia, Plovdiv Branch, 26-28 May 2022. (AIP Conf. Proc. 2980, 2024). DOI: 10.1063/5.0184231, ISBN: 978-073544814-8.

[12] H. Metev, Krumov K. Determination of Accuracy in Finishing Machining Trough Surface Plastic Deformation with Account of the Phenomenon of Technological Heredity. In: 12th International scientific conference “TechSys 2023”- Engineering, Technologies and Systems, Technical University of Sofia, Plovdiv Branch, 18-20 May 2023 (AIP Conf. Proc. 3078, 2024). DOI: 10.1063/5.0208291, ISSN: 0094243X.

[13] H. Klaus, F. Hetzelt, P. Hofmann, A. Blecker and D. Schwaiger, 'Challenges and Solutions for Industry-Grade Secure Connectivity', 2019 International Conference on Networked Systems (NetSys), Munich, Germany, 2019.

[14] M. Marinov Jordanov, Vector-Matrix Computer Method for Drafting Circling-Point Curves and Centering-Point Curves of Burmester, Vide. Tehnologija. Resursi - Environment, Technology, Resources, Volume 2, Pages 440 – 443, 2024, 15th International Scientific and Practical Conference on Environment. Technology. Resources, ETR 2024, Rezekne, 27 June 2024 through 28 June 2024, Code 201245, Conference Proceedings, ISSN 16915402, ISBN 978-171389957-0, DOI 10.17770/etr2024vol2.8072.

[15] M. Marinov, Jordanov, Synthesis of Eight Middle Lost Mechanisms Finally Discharged Discreet Positions, Vide. Tehnologija. Resursi - Environment, Technology, Resources, Volume 2, Pages 435 – 439, 2024, 15th International Scientific and Practical Conference on Environment. Technology. Resources, ETR 2024, Rezekne, 27 June 2024 through 28 June 2024, Code 201245, Conference Proceedings, ISSN 16915402, ISBN 978-171389957-0, DOI 10.17770/etr2024vol2.8067.

[16] M. Marinov, A Geometrical synthesis of comez textile machanisms of finally removed possibilities, Environment. Technology. Resources. Rezekne, Latvia Proceedings of the 14th International Scientific and Practical Conference. Volume 3, pp. 168-171, ISSN 1691-5402.

[17] M. Schillings, Strategic Management of Technological Innovation, Ravi Shankar, Edition: 6, 2019.

[18] M. Sain, Y. J. Kang and H. J. Lee, 'Survey on security in Internet of Things: State of the art and challenges', 19th International Conference on Advanced Communication Technology (ICACT), Bongpyeong, 2017.

[19] N. Kolev; Aleksandrova I, Metev H. Modeling and Optimiza-tion of Tool Life When Machining 42CrMo4+QT Steel on Swiss-Type CNC Lathes. In: 33rd International Scientific Symposium Metrology and Metrology Assurance, MMA 2023, Conference Proceedings, Sozopol 7-11 September 2023,Code 194604, DOI: 10.1109/MMA59144.2023.1031792, ISBN: 979-835033810-2.

[20] S. Mumtaz, A. Alsohaily, Z. Pang, A. Rayes, K. F. Tsang and J. Rodriguez, 'Massive Internet of Things for Industrial Applications: Addressing Wireless IIoT Connectivity Challenges and Ecosystem Fragmentation', IEEE Industrial Electronics Magazine, vol. 11, no. 1, pp. 28-33, March 2017.

[21] J. Sunbi, Gallina A., Contemporary Management of Innovation: Are We Looking at the Right Things?, USA, 2019.

[22] I. Mitev, Optimizing the quantity of liquid phase at the sintering of powder construction materials from system Fe-Cu-Sn, 11th International Scientific Conference “TechSys 2022” – Engineering, Technologies and Systems, AIP Conf. Proc. 2980, https://doi.org/10.1063/5.0184238 , Published by AIP Publishing. 978-0-7354-4814-8/$30.00, pp. 060017-1 to 060017-7.

[23] I. Mitev, Determining the diffusion coefficient in simultaneous saturation with boron and carbon of austenite alloyed with cooper in powder metallurgy structural materials, 11th International Scientific Conference “TechSys 2022” – Engineering, Technologies and Systems, AIP Conf. Proc. 2980, 060016-1–060016-8; https://doi.org/10.1063/5.0184239 , Published by AIP Publishing. 978-0-7354-4814-8/$30.00, pp. 060016-1 to 060016-8.

[24] T. Kuzmanov, K., H. Metev, I. Tsvyatkova. Morphological method application to designing modular sectional tools systems. International scientific conference UNITECH’03, Gabrovo, Bulgaria 2003, vol.1. pp. 544-546. ISBN 954-683-167-0.

[25] S.Tsenkulovski, Mitev, I., Influence of the Parameters of the Laser Marking Process on the Depth of Penetration in Layer-reinforced Composites, Vide. Tehnologija. Resursi - Environment, Technology, Resources, Volume 3, Pages 319 – 324, 2024, 15th International Scientific and Practical Conference on Environment. Technology. Resources, ETR 2024, Rezekne, 27 June 2024 through 28 June 2024, Code 201245, Conference Proceedings, ISSN 16915402, ISBN 978-171389957-0, DOI 10.17770/etr2024vol3.8147.

[26] G. Chipriyanova, Atanasov, A., Krasteva-Hristova, R., Environmental Management for Sustainable Business in Chemical Industry in Bulgaria, Vide. Tehnologija. Resursi - Environment, Technology, Resources, Volume 1, Pages 95 – 101, 2024, 15th International Scientific and Practical Conference on Environment. Technology. Resources, ETR 2024, Rezekne, 27 June 2024 through 28 June 2024, Code 201245, Conference Proceedings, ISSN 16915402, ISBN 978-171389957-0, DOI 10.17770/etr2024vol1.7971.

[27] G. Chipriyanova, Chipriyanov, M., Luchkov, K., Investigation and Analysis of Attitudes Towards the Implementation of Artificial Intelligence in Internal Business Processes, Vide. Tehnologija. Resursi - Environment, Technology, Resources, Volume 2, Pages 61 – 67, 2024, 15th International Scientific and Practical Conference on Environment. Technology. Resources, ETR 2024, Rezekne, 27 June 2024 through 28 June 2024, Code 201245, Conference Proceedings, ISSN 16915402, ISBN 978-171389957-0, DOI 10.17770/etr2024vol2.8032.

[28] G. Chipriyanova, Marinova, M.., Technological Aspects of Accounting Automation System as a Decision Support System, Vide. Tehnologija. Resursi - Environment, Technology, Resources, Open Access, Volume 2, Pages 28 – 33, 2023, 14th International Scientific and Practical Conference on Environment. Technology. Resources, ETR 2023, Rezekne, 15 June 2023 through 16 June 2023, Code 191610, DOI: https://doi.org/10.17770/etr2023vol2.7309 .

[29] A. Kocilovii, I R.K. Madsteriakova – 4 izd., prerab. Idop., Spravochnik tehnologa-mashinostroitelia – Tom 2, Moskva, Mashinostroenia, 1985.

[30] An. Lengerov, “Algorithmic model of technical and economic calculation of optimal technological process “Manufacturing Technologies (part XI), 2016, vol.26. pp. 94-96. ISSN 1312-8612.