

Design of Special Clamp for Manipulating with Tools, Micro and Nano Objects

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Abstract. This work examines a three-finger clamp for manipulating with tools, micro and nano objects. The operation is performed by piezo-ceramic actuators. Optional types of methodology for their design, both through a displacement analysis by FEM software package and through a selection of eligible pseudo-optimal solutions using neural networks, are proposed. The authors examine a specific structure, using many different materials and founding those which guarantee given deformation, causing displacement of each finger of the set, provoked by similar forceful impact on the elements of the clamping frame. The aim is to create an algorithm of design of similar clamping devices.

Keywords: special clamp for manipulating with tools, micro and nano objects (clamping device); deformation/displacement analysis; finite element method (FEM); SolidWorks; neural networks (NNs)

1. Background of the Problem

In the 20th century robotics reached high excellences in all spheres of industry and to some extent in everyday life. In the late 20th century the development of robotics for micro/nano manipulation processing began. We observe rapid development of robotic operations in the fields of microsurgery, microbiology, cellular and molecular biology, microelectronics, etc. at present. Most of them can never be realized manually or with reasonable accuracy.

For the purposes of micro/nano operations a new type of robots with appropriate manipulating systems (MS) and clamping devices, with new controlling configurations and sensors ([4], [5], [6], [7], [8]) have been developed. The need of smaller displacements, greater accuracy and resolution in the nanometers has led to the use of new type actuators - electro-mechanical or electro-magnetic piezo-actuators ([7], [6], [9]).

A three-finger clamp, called also "clamping device", for micro and nano objects and tools, realized by three identical modules, arranged in 120° (Figure 1a) is used in special developed force sensor in micro and nano N range [10]. Each of the modules implements radial moving of its finger, not greater than tenths of a millimetre, by deformation of its elements. Piezo-ceramic actuators, causing elements deformation, are integrated in these modules.

2. Aim of the Study

The aim of the study is to perform stress and deformation analysis of the frame of the described clamping device. It is sufficient to examine only one of the three modules due to their identity. As noted above, the gripping of microobjects is achieved by the deformation of the three major modules arising to operation by the built in them piezo-ceramic actuators. As a result of the process of deformation a micromovement of each finger, named later "proboscis", is carried out. The task is to generate a set of materials which guarantee a given displacement at a given load/force impact on the frame of the clamping

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device. By modern computational methods and software products ([11]) using finite element method (FEM) ([12]) a more precise computer modelling of stress, strain and displacement distribution in structures and identification of endangered areas is possible. In combination with the newer numerical methods such as neural networks (NNs) ([3]), the finite element method can be transformed into a powerful mathematical tool for solving design problems in many scientific and industrial fields.

The ultimate aim of the authors is to create an algorithm of design of similar clamping devices.

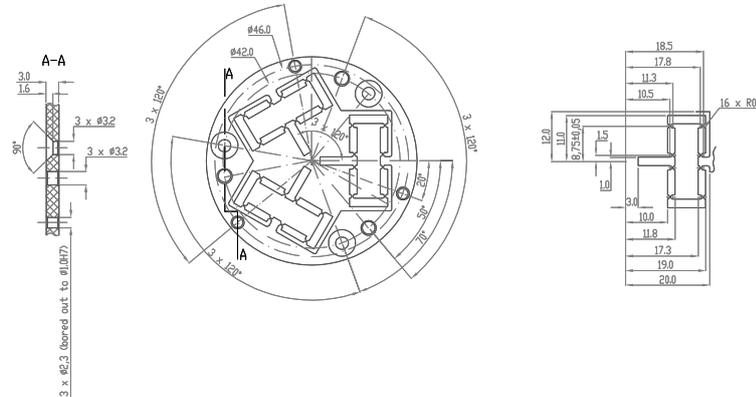


Fig. 1c: Section of the clamp.

Fig. 1a: Drawing of the clamp.

Fig. 1b: Drawing of the studied module.

Fig. 1: Drawing of one unit of the clamping device.

3. Description of the Model

Figure 1 shows a drawing of the clamping device. The three modules according to the drawing in figure 1 are located at 120° and implement the grip of the microobject. A piezo-ceramic actuator, acting by uniformly distributed force on both side surfaces of the module (Figure 1b), causes almost instant deformation of the module and moves the finger. This enables us to accept that the forceful impact is constant over time.

A 3-dimensional (3D) model of the module using the existing design documentation has been created through software SolidWorks. Then the 3D model has been transformed to a model of spatial finite elements, through software package SW-Simulation. This toolbox has generated the finite element model using spatial tetrahedrons of first order. The stresses, strains and displacements of the finger have been calculated for this model. Defined boundary conditions have been set as follows: attachment at the screw openings-type "fixed" and attachment at the boundary surfaces to the two adjacent modules - type "circular symmetry" (Figure 2).

Two options of loading the module exist:

- The loading is realized by «Force» loads, distributed over predefined surfaces, where the magnitude of the equivalent force is introduced. It has been assumed that the surface loads are uniformly distributed and the magnitude of their equivalent force, corresponds to the impact of the piezo-crystals on the frame surfaces;
- The loading depends on the course of the actuator that is in contact with the corresponding surfaces in its initial non-loading position. This option has been required because the course of the piezo-ceramic actuator is known with greater precision than the impact generated force. Knowing the maximum deflection and using the well-known relations, the values of the distributed surface loads that have given rise to, have been calculated.

The formulated problem is related to the problems of synthesis, but because of its numerical interpretation is solved through analysis methods. Input data is organized into two sets: proposed set of different types of suitable materials, introduced by their modules of elasticity and coefficients of Poisson and a set of loading, including the known values of the forces or the displacement values as functions of actuators course. Combinations between two data sets are infinite, so it is appropriate to use neural networks to offer a range of possible solutions.

The number of eligible solutions is limited by the following criteria: radial displacement of the "proboscis" is set between predefined limits and its exact maximal value is monitored; stresses in the critical areas of the studied module are below the admissible values. Extraction of pseudo-optimal options from the set of eligible solutions is made according to the following criteria: minimum stresses in critical areas; minimum course of the actuator for the desired value of the "proboscis" displacement.

Regarding the limited volume of the publication, the authors will illustrate the proposed algorithm by a set of materials and a force equal to 900N (Figure 2).

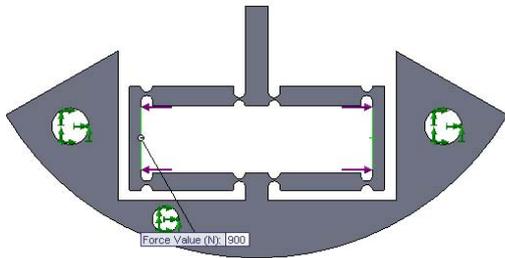


Fig. 2: 3D model of the loaded clamping module.

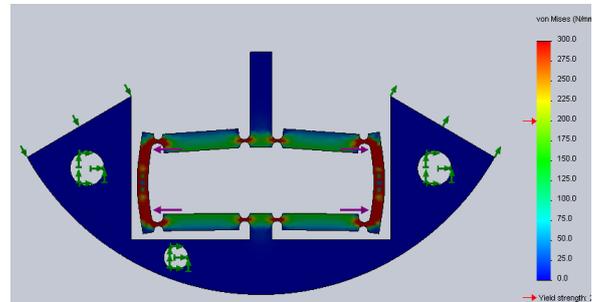


Fig. 3: Distribution of the von Mises stress in the studied module.

4. Solution for a set of Materials

To find a suitable material some of the material constants, particularly the ones determining the deformation of the module such as modulus of elasticity - E , Poisson ratio - μ and the associated to them shear modulus G are varied. The modulus of elasticity and Poisson ratio are set as input data.

Distribution of von Mises stress, shown in Figure 3, enables easy determination of stress endangered areas. Consequently, it is possible to seek a change of the underlying structural dimensions. The radial displacement of nodes of the vertexes of the surface of the „proboscis” is monitored.

The following figures show graphical and numerical results of the module analysis through finite element method. Material characteristics of pure aluminum, aluminum alloys, plastics, etc. are introduced as input data. Figure 4 shows nodal displacements along, vertical for this scheme, axis as for the studied “proboscis” they coincide with the radial displacements towards the center. “Loop” shows the non-deformed shape of the module. It can be seen that when a suitable material is introduced, the surface of the “proboscis” moves towards the center of the clamp and thus sustainable gripping of the manipulated tool or nanoobject can be achieved.

The finite element numerical experiments are conducted in the following three stages:

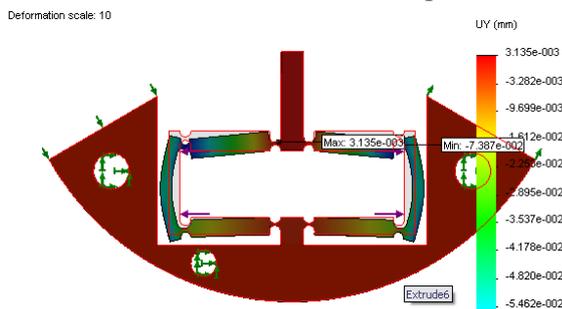


Fig. 4: Distribution of the nodal displacement in finite element model towards center - non-deformed and deformed shapes.

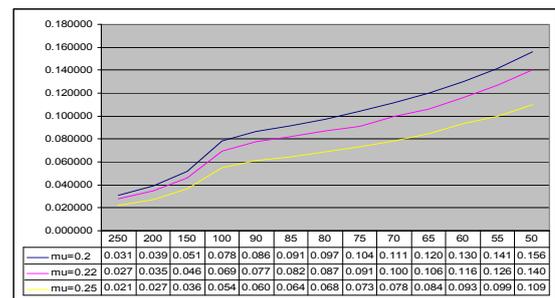


Fig. 5: Graph of averaged radial displacement of the surface of the "proboscis" while modulus of elasticity E is varied.

- Stage I: Modulus of elasticity E is varied. The obtained results are summarized in Figure 5.
- Stage II: Poisson ratio is varied

To refine the study Poisson ratio is additionally varied. For pure aluminum it is equal to 0.22, for aluminum alloys – it is around 0.3.

- Stage III: Additional studies

In numerical simulation using free-cutting brass with material characteristics: $E = 97\text{GPa}$, $G = 37\text{GPa}$ the average monitored displacement of the surface is 0.11767 mm.

- Stage IV: Model of Neural Network (NN)

After testing a set of materials through FEM and establishing of one-direction relation: the magnitude of the force, the modulus of elasticity and Poisson ratio of the material on one side and the radial displacement of the "proboscis" corresponding to initial input data, as described in the previous items, on the other side, a neural network of type: Fitting Function is set up.

In the cited case, the input data includes the magnitude of the force, modulus of elasticity and Poisson ratio of real materials. The target data includes the radial displacements of the "proboscis" obtained through FEM. All available data sets are divided as follows: 70% of data sets are for training of the network (27 samples), 15% of data sets are for testing of the network (6 samples) and the remaining 15% of data sets (6 samples) are used to verify its reliability. The training samples are presented to the network during training, and the network is adjusted according to its error. Testing samples have no effect on training and so provide an independent measure of network performance during and after training. The validation samples are used to measure network generalization, and to halt training when generalization stops improving.

The created neural network is realized through software product MatLab, package Neural Networks ([2], [1]). It has 10 hidden layers.

After training and passing through all necessary checks the network is used to calculate the radial displacements of the "proboscis" for 196 other materials, included in the standard material library of SW-Simulation, such as different alloys, non-metal materials and some plastics. The result is a set of the averaged radial displacement of the "proboscis". Developed software module automatically removes all outcomes that do not meet the predefined displacement criterion, i.e. radial displacement of the "proboscis" to be $\geq 0.1\text{mm}$. Thus the neural network itself ensures compliance with the first optimization criterion. Unfortunately, only some of the pre-selected materials satisfy this criterion.

When these calculations use traditional solving methods for static problems (for example FEM for static analysis of three-dimensional objects), they consume much more computer time and human resources.

Best validation performance of neural network calculation is described by mean square error (MSE) of the network. Mean square error is the average squared difference between outputs and targets. Lower values are better. Zero means no error. The defined tolerance of $1.5e^{-7}$ is achieved in 15 epochs. The process of network training is monitored through gradient, validation checks, etc. Regression values R measure the correlation between outputs and targets. Finally the error histogram is obtained.

- Stage V: Follow-analysis of the module

Practically the exact value of the force by which the actuator acts on the module is not known. Because of this more correct formulation of the problem would be: What kind of material can achieve the predefined displacement of the "proboscis" and initially given yielding stress safety factor for a given course of the actuator, which corresponds to the deformation of frame walls of the module. Particularly, this problem can be re-defined as follows: What type of material, characterized by its physical parameters/material constants can realize a radial displacement of the "proboscis" (finger) bigger than 0.1mm at a course of the actuator equal to 15 microns, i.e. the analyzed module works like a multiplier of the displacement.

Since, the created model and the used software do not allow such a redefinition of the problem, so the solution of the problem for such initial settings remains a subject of authors' further research.

5. Conclusions

Based on the performed numerical experiments the following conclusion can be made: Reduction of the modulus of elasticity and Poisson ratio increases the radial displacement of the "proboscis", while it does not depend on density, yielding strength, and some other material characteristics. Designed displacement can be

achieved by some alloys. The authors' research is fixed to aluminum alloys in particular. Another suitable material is brass. Alternatively, the authors focus their attention plastics, particularly ABC plastics. Due to their higher degree of deformation, they require nonlinear static analysis. *Based on the existing wide range of plastics and the development of material science and technology, the authors believe that plastics are and will be beneficial material for use in similar clamping devices.* Finally, the authors state that *a comprehensive solution of this problem of structural design can be obtained by combining software running different versions of FEM with those based on NNs.* This combination results in strong reduction of computer and human resources and time.

6. Acknowledgements

This work was partially supported by the Bulgarian NSF in the framework of SpiCy-MiNT project under contract No. DOI TK171/08.

7. Reference

- [1] Beale M., M. Hagan and H. Demuth: *Neural Network Toolbox™ 7, User's Guide*, 2010, www.mathworks.com
- [2] Hagan M., H. Demuth, M. Beale: *Neural Network Design*, 2002.
- [3] Haykin S.: *Neural Networks: A Comprehensive Foundation*. Prentice Hall, 1998, 2nd edition.
- [4] Ionescu Fl., K. Kostadinov, R. L. Hradynarski: Operation and Control of a 6,5 DoF Micro and Nano Robot for Cell Manipulations, *Proceeding of the Mechatronics and Robotics Conference*, 2004. Aachen, Germany.
- [5] Kostadinov K., Fl. Ionescu, R. L. Hradynarski, T. Tiankov: Robot Based Assembly and Processing Micro/Nano Operations, *Proceeding of the 4M2005, 1st International conference on Multi- Material Micro Manufacture*, 2005, Karlsruhe, Germany.
- [6] Kostadinov K., R. Kasper, M. Al-Wahab: Control Approach for Structured Piezo Actuated Micro/Nano Manipulator, *IUTAM Symposium*, 2005, Munich, Germany.
- [7] Kostadinov K., R. Iankov, Fl. Ionescu, P. Malinov: Analysis of 2 DoF Piezo Actuated Joint Utilizing in the Robot for Micro and Nano Manipulations, *Romanian Journal of Applied Mechanics*, 2004, vol. 49.
- [8] Tiankov T., A. Shulev, N. Elian, D. Chakarov, I. Roussev, M. Al-Wahab, K. Kostadinov: Experimental Motion Study of the Mehchatronic System for Manipulation and Processing Micro/Nano Operations, *Nanoscience & Nanotechnology*, vol. 6, Heron Press Science Series, 2006, Sofia, Bulgaria.
- [9] Tiankov T., A. Shulev, D. Gotzeva, I. Roussev, K. Kostadinov, Investigation of Piezo Actuated Micro/Nano Manipulator by Digital Speckle Photography and Interferometry, *Proceedings of the International Conference on Automatics and Informatics' 06*, 2006, Sofia, Bulgaria.
- [10] Kostadinov, Robot Technology in Hybrid Assembly Approach for Precise Manufacturing of Microproducts, *Proceedings of the 12th Mechatronics Forum Biennial International Conference June 28-30, 2010*, Swiss Federal Institute of Technology, ETH Zurich, Switzerland, Book 1, pp. 293-300.
- [11] *SolidWorks Simulation Training Manual*, 2010, & *SolidWorks – Users Manual*, 2009, Dassault Systemes SolidWorks Corporation, Massachusetts, USA.
- [12] Zienkiewicz O. C., *Finite Element Method in Engineering Science*, McGraw-Hill Inc., 1972, US, 2nd edition.