

## STUDY THE EFFECT OF VIBRATION ON THE MICRO-ASSEMBLIES FOR INSTRUMENT DEVICES

ALEXANDER NIKOLAEVICH LITVINOV<sup>1</sup> & AUDAY SHAKER HADI<sup>2</sup>

<sup>1</sup>Professor, Department of Theoretical and Applied Mechanics, PSU, Penza, Russia

<sup>2</sup>Research Scholar, Department of Mechanical Engineering, University of Technology, Baghdad, Iraq

### ABSTRACT

Mathematical simulation of dynamic processes of micro-assemblies instrument devices elements is an actual issue, allowing accept design and technological solutions to ensure the required level of vibration strength and vibration stability of micro-assemblies in operating conditions in the early stages of design. The aim of the work is to increase reliability and provide tactical and technical characteristics of the instrument devices through the design and technological methods. Micro assembly is considered as a spatial heterogeneous structure subjected to the vibration loading. Modeling of dynamic processes in micro assembly elements with the fulfillment of numerical methods using finite element software package ANSYS. There was developed a modeling software complex and numerical study of the spectrum of natural frequencies and the stress-strain state of the micro assemblies' elements under the vibration loading was carried out. The effect of different typical sizes of micro assemblies on the wave shapes and spectrum of natural frequencies was studied, as well as the position of the most loaded zone of the micro assemblies' elements where emergence and development of latent defects is possible. Numerical studies which have been carried out showed that in order to provide vibration resistance and stability of metrological characteristics of micro assemblies it is necessary to carry out mathematical modeling of micro assemblies elements state under real operational effects at the design stage.

**KEYWORDS:** Instrument Devices, micro-assembly, Heterogeneous Structure, Natural Frequencies, Wave Shape, The Stress-Strain State, Vibration Resistance, Vibration Strength

### INTRODUCTION

One of the most important tasks for the developing of the scientific principles of design and the technology of manufacturing the articles of various applications is the creation of adequate mathematical models describing the state of structures and their elements in their manufacturing, testing, transportation, storage and operation. The analysis of failures relating to devices and their components proves that static, dynamic and thermal effects arising at all stages of the product life cycle are the main types of effect. [1, 2].

The analysis of the design features of modern instrument making devices and theirs components shows that the majority of them are heterogeneous structure combining the materials with different physical and mechanical properties, that ensure the required reliability and safety of the device in the specified operating modes [3,4]. In order to study the processes taking place in the structures of such devices under the influence of the external factors, it is necessary to develop the mathematical models and complexes of problem-oriented programs for simulation experiments allowing describing adequately the processes and strain-stress state (SSS) at all stages of their operational lifetime.

## MATERIALS AND METHODS

Micro assembly is considered as a spatial heterogeneous structure subjected to the vibration loading. Modeling of dynamic processes in micro assembly elements with the fulfillment of numerical methods using finite element software package ANSYS.

### Model Used for the Study of the Dynamic Characteristics

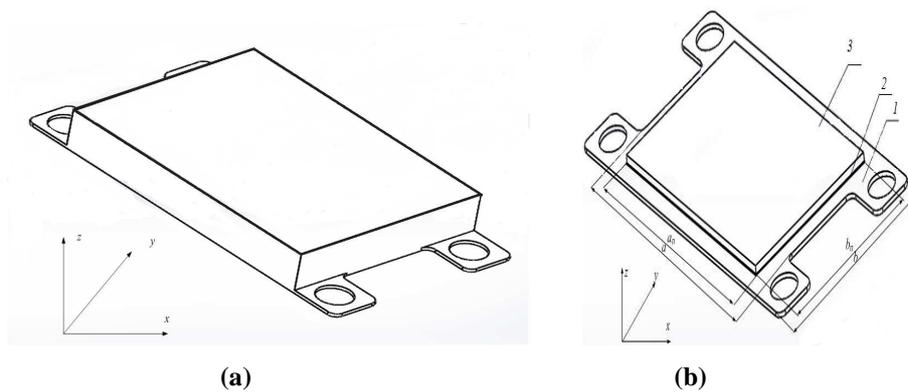
Let us explore micro-assembly of rectangular type that have a wide practical application in instrument engineering and radio electronics devices. The circuit boards and resistive elements are located on one or several planes inside the micro-assembly providing the required output parameters of micro-assembly. These micro-assemblies are multilayer heterogeneous systems that are exposed to various thermal and mechanical effects during their manufacture and operation. In order to check their impermeability during manufacture, they are exposed to the technological pressure testing with external excess pressure; as a result of such a test the deformation of planes of the case and the circuit boards with resistive elements; that affects the change in their metrological parameters.

For the analysis of S.S.S. and their micro assemblies elements there have been offered various models, allowing to explore their status during pressure testing technology of the case and determine the maximum allowable pressure considering their design features [5,6] being scientifically proven. Similar researches were carried out under thermal technological and operational effects on the micro assemblies [7]. Issues relating to simulation and studying the dynamic processes taking place in micro assemblies under the vibration are not enough investigated nowadays [8].

Let us consider an external dynamic effect on micro- assembly. Standard design for micro-assemblies of the rectangular type is shown in Figure 1. Micro-assembly is fastened by screws to the device in four points, and has overall dimensions of case on axes  $x,y,z$  respectively  $a \times b \times H$ , where  $a \times b$  are dimensions given in the plan ;  $H$ - a case height . The circuit board is located on the base of the case (Figure 1b) with thickness  $h$  and dimensions given in the plan  $a_n \times b_n$ . The circuit board is connected to the base with soldered seams or adhesive joints with thickness  $h_m$ . The material of circuit board is characterized by the elastic modulus  $E_n$  and Poisson's ratio  $\nu_n$ ; the material of the seams are characterized by shear modulus  $G_m$  and Poisson's ratio  $\nu_m$  .

In general case, it is considered that the planes of micro-assembly case are made of various materials the mechanical properties of which are characterized by elastic modulus  $E_j$  with thicknesses  $h_j$ , where  $j = 1, 2, 6$  the number of the plane. To be specific, assume that  $j = 6$  corresponds to the case cover,  $j = 1$  – base with the circuit board,  $j = 2...5$  to the side walls of the case.

It is considered that harmonic vibration effects the micro assembly from the case in the  $z$  direction, under which while being operated on resonance phenomena is possible. The latter can take place in the micro assembly elements (covers, side walls, a base, a circuit board, a seam).



**Figure 1: The Design of micro assembly; a- General View; b- Base With The Circuit Board: 1-Base, 2-Seam, 3- Circuit Board**

Spatial model of micro-assemblies in the form of heterogeneous structure together with the finite element method is used as an adequate model allowing exploring the dynamic processes in the elements of micro assemblies implemented in the software package ANSYS similarly [6]. This model allows considering the mutual influence of the case planes, the real sizes of the boards and their location on the base, and the influence of physical and mechanical characteristics of the materials used in the boards, the seam and case planes. The model allows to take into account several multilayered circuit boards put inside the case, including those ones which are located on different case plane. It can lead to the lack of symmetry in the design of micro-assembly and the loss of its S.S.S simplicity. The offered model is spatial and the most common in comparison with models described in [2].

## RESULTS AND DISCUSSIONS

According to the proposed model the dynamic characteristics of various types and sizes of micro-assemblies were studied. It is found that the wave shapes of micro-assemblies, their natural frequency and the location of the most loaded zone of their elements where the occurrence and development of defects is possible essentially depend on the dimensions of micro assemblies and features of their design: numbers and sizes of the boards, the micro assembly height. In particular while increasing the height of the micro-assembly flexural and torsional shape of natural vibrations are occurred, where the most loaded zone are located on eyelets through which micro-assembly is attached to the device. This is due to the displacement of mass center of the micro-assembly while increasing its height.

As an example we can take some results of the numerical simulation of dynamic characteristics for the micro assembly with the following dimensions:  $a \times b \times H = (36 \times 24 \times 5)$  mm. The circuit boards are located in the center of the base and fixed thereto by glue BK -9. The case is manufactured of alloy 29HK ( $E_j = 1,4 \cdot 10^5$  MPa,  $\nu_j = 0,3$  while  $j = 1, 2, \dots, 6$ ); circuit boards are made of pyroceram ( $E_n = 9,693 \cdot 10^5$  MPa,  $\nu_n = 0,25$ ), and the properties of the seams are characterized by the shear modulus  $G_m = 1000$  MPa. The thicknesses of the micro assembly elements taken as follows:  $h_j = 0,4$  mm (при  $j = 1, 2, 6$ );  $h = 0,6$  mm;  $h_m = 0,1$  mm. Two micro-assemblies were considered:

I design: the circuit board has the dimensions  $a_n \times b_n = (30 \times 20)$  mm;

II design: the circuit board has the dimensions  $a_n \times b_n = (15 \times 10)$  mm.

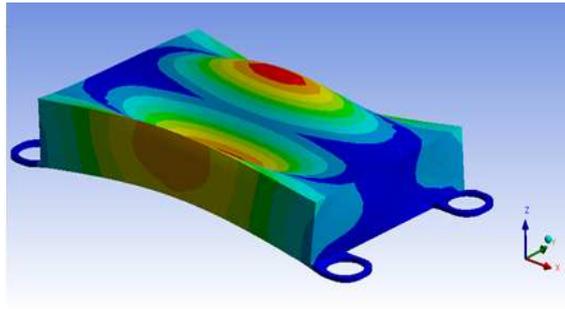
Table 1 for the considered micro-assemblies shows the values of the first eight natural resonant frequency and indicate to the most loaded micro-assembly resonating elements corresponding to each frequency.

The analysis of the spatial animated pictures for the deformation of micro-assembly elements showed:

The main resonating elements are the cover and the base with the board;

The main wave shapes of the cover and the base with circuit board are their flexural vibrations;

At frequencies marked with an asterisk (\*) there has been observed flexural and torsional vibrations of the whole micro-assembly at axis x: for micro-assembly I  $f_* = f_8 = 10938$  Hz, and for micro-assembly II flexural and torsional vibrations occur at a higher frequency  $f_* = f_{14} = 14967$  Hz (Figure 2);



**Figure 2: Flexural and Torsional Vibrations of the micro-assembly I ( $f_* = 10938$  Hz)**

The value of the resonant frequency of the micro-assembly elements and their corresponding wave shapes of the most loaded elements depend essentially on the size of the circuit board installed on the basis. While decreasing the circuit boards size the value of resonance frequency decreases, because the rigidity of the base with the circuit boards decreases;

The most dangerous phenomena are the resonance arising at the base with the circuit board, because in this case the occurrence and development of defects in the form of micro-cracks in the adhesive (or soldered) seams are possible, as well as deterioration of the metrological characteristics of the micro-assembly because of the increased strain resistive elements located on the surface of the circuit boards.

Figure 3 for micro-assembly II shows the first five wavemode shapes, characterizing vertical deflection in the direction of the axis z. The side walls of the case in Figure 3 are not conventionally shown.

In Figure 4 there have been shown SSS of the main elements of micro-assembly II for the first five shapes of natural vibrations and the point in which the equivalent stresses calculated by Mises criterion [2] reach the maximum value. Acceleration amplitude acting on the micro-assembly in the direction of axis z, is taken as 10g, where g is acceleration of gravity. The side walls of the micro-assembly are conventionally not shown in Figure 4.

The numerical simulation of the SSS carried out for various frame sizes of micro assemblies showed as follows:

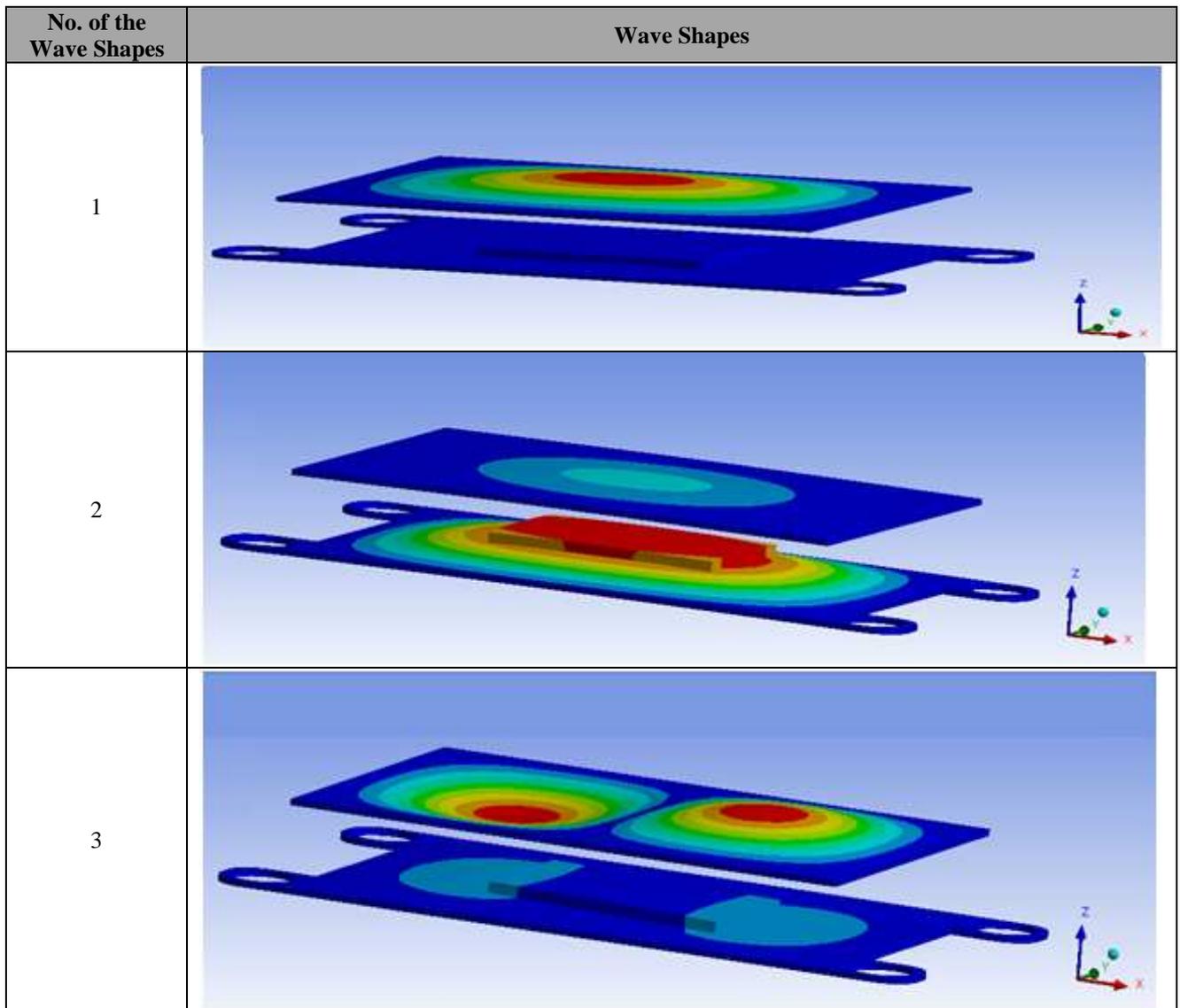
Depending on the external frequency most loaded elements of the micro assembly are the cover, the base, the circuit boards and the seams connecting the board with the base;

SSS depends essentially on the geometric dimensions of the case and the board as well as the frequency of external influence;

The place of the most loaded zone structure is significantly determined by the wave shapes, implemented in the structure under the dynamic influence as well as the size of the board and the micro-assembly case.

**Table 1: Natural Frequencies  $F_j$  and Resonating micro-assembly Elements**

Number of Frequency J	Microassembly I		Microassembly II	
	$f_j$ (Hz)	Element	$f_j$ (Hz)	Element
1	3252	cover	3210	cover
2	5234	cover	4028	cover and base with the circuit boards
3	5671	base with the circuit boards	5181	cover and base with the circuit boards
4	7362	cover	6286	cover and base with the circuit boards
5	8478	cover	7301	cover and base with the circuit boards
6	10010	cover	8454	cover
7	10125	base with the circuit boards	8769	cover and base with the circuit boards
8*	10938	cover and base with the circuit boards	9953	cover



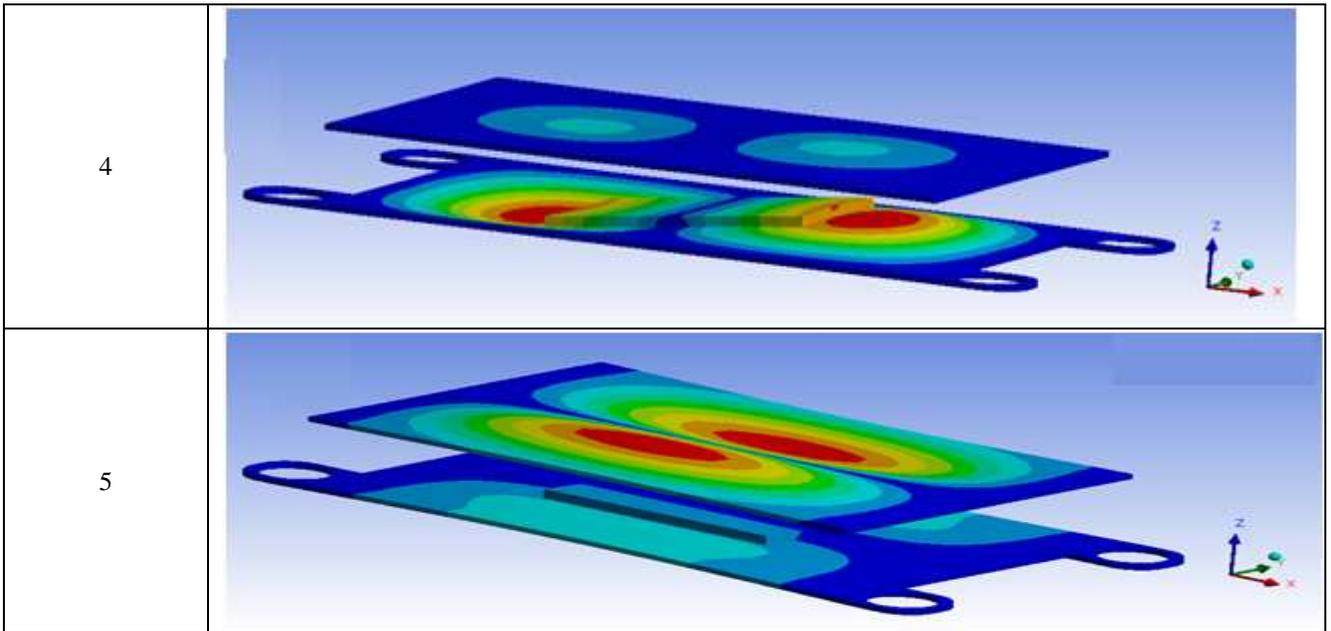


Figure 3: Wave Shapes for micro assembly II

No. of the Wave Shapes	SSS Elements
1	
2	
3	

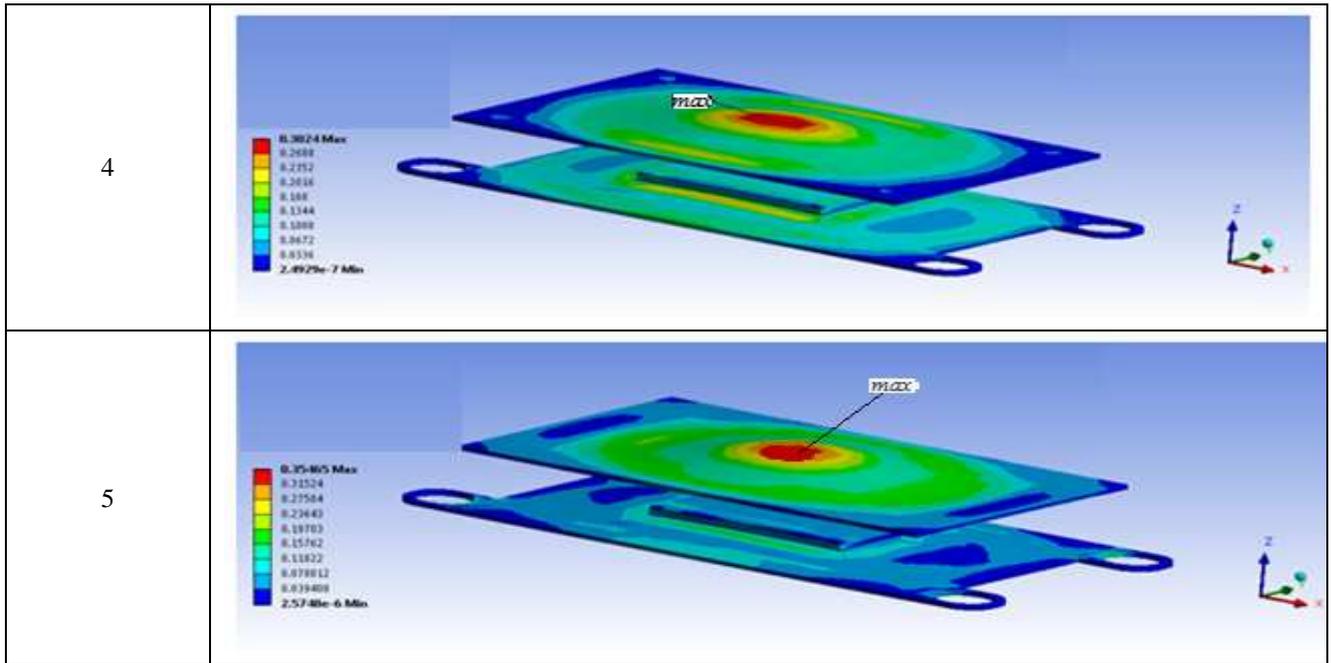


Figure 4: SSS for micro assembly II Elements

## CONCLUSIONS

The development and application of the mathematical models and program oriented computer systems allow providing the required reliability and vibration resistance of the structures at the earliest stages of designing and implementation of the technological processes of the manufactured micro-assemblies which provide the specified performance characteristics of the devices in the operational mode. The selection of simulation mathematical model and its level of complexity (one-dimensional, two-dimensional, three-dimensional, with the consideration of heterogeneity and other design features) are determined by the structural features and the required accuracy of the SSS analysis in regard to the designed structure.

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