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MICROMANIPULATION AND MICRO COMMUTATOR SYSTEMS BASED ON PIEZOELECTRIC MATERIALS

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Résumé : *In this paper, specific applications dedicated to micro systems are designed to perform micro manipulation tasks intelligently and efficiently. The first approach proposed is a micro manipulator called micro gripper, which is used to manipulate micro objects whose maximum size is 1mm. These useful and sometimes essential devices are designed to perform micro assembly operations or to position a micro object using a microscope after visualization. these micro components with high precision of less than 1 µm. The second approach proposed consists of two applications in the field of micro connections. One of them is a micro beams embedded at one of these extremities and free at the other of the cantilever type. The other one is a structure embedded at the two extremities of the bridge type. These micro beams form the micro commutator. The purpose of our work is to model the deflection of the micro beams proposed under the effect of an external stress based on the electromechanical characteristics of the piezoelectric materials to have a good manipulation of the micro systems and a good connection of the micro commutator. In the course of the work, the performance of these components and for which applications they seem most appropriate will be presented.*

Mots clés : *finite element method; Piezoelectric actuator; Micro manipulation; Micro gripper; micro commutator.*

1. INTRODUCTION

Over the past ten years, the scientific community has studied micro manipulation and microassembly devices [1]. These devices are designed to manipulate micro components smaller than 1 mm in different fields as the assembly of micro-mechanisms [2, 3], laser sources, optical benches [4, 5] and the manipulation of biology cells or cosmetic powders. Their field of application is vast, it includes micro mechanics, micro electronics, micro systems, micro optics as well as medicine, biology and pharmacy. Assembly and Manipulation are extremely different problematic from each other depending on whether we consider microscopic objects or millimeter-sized objects [6, 7].

Thus, they cause several problems for the manipulation of micro objects. For this reason, lots of research companies are working to study, model and control adhesion forces [8, 9]. This step is particularly necessary for automatically programming micro manipulation tasks. As for the solutions, we can either minimize the adverse effects of adhesion or using them wisely. In addition, micro objects are generally very fragile (specific materials, small size), which require mastery of sollicitations during a micro manipulation operation. Similarly, visualization has to be done using a system with a resolution which is compatible with the size of the objects manipulated. Thus, optical microscopes and scanning electron microscopes are widely used.

the spaces require a compact visual system such as a fiberscope or a micro camera. Currently, micro-assembly is notably carried out with high precision personalized systems (inflexible and expensive) or manually by highly qualified technicians. Numerous research is being developed to provide solutions for large series of products such as: parallel assembly [2] [10] and self assembly [11, 12] as well as for small series such as: series assembly with manipulator robots and micro factories which capable of carrying out processes in complete flexibility for small series.

The aim of this article is to demonstrate the enormous interest in using system materials and precisely intelligent piezoelectric materials. The property of generating a mechanical constraint from an electrical potential and vice versa (direct and indirect effect) offers possibilities to use this type of material as sensors or actuators existing in many forms of transducers. The sensor converts mechanical energy into electrical energy for monitoring purposes, and ordinarily the actuator converts electrical energy into mechanical displacement.

To achieve this objective, the following section has been organized as follows:

In the context of micro manipulation and micro assembly, the first part contains one of the devices used for picking and placing operations, it is the micro gripper. A micro gripper consists of two simple beams actuated by intelligent materials. Piezoelectric intelligent materials are the most used to actuate micro grippers. Such recognition is essentially due to their high precision, high speed and high force density. For example, Haddab et al. [13] proposed a piezoelectric type micro gripper which offers a positioning range of some tens of micrometers and a stabilization of some milliseconds of time. Menciassi et al. [14] also presented a piezoelectric type micro gripper with a force sensor used for force controlled manipulation [15]. Kemper [16] suggested a micro gripper that contains a force sensor and actuated by piezoelectric stacks. A pneumatic micro gripper has been proposed in [17]. Finally, a micro gripper can parallely be actuated by the principle of stick and sliding movement as in [18]. Shape memory alloys (SMA) based on crystalline displacement (deformation) caused by a temperature variation between two phases, a ductile phase and a high resistance phase [19, 20], this type of material has also been used for the development micro grippers with integrated force sensors [21]. The main advantage of these materials relative the design of piezoelectric materials is the large range of positioning (more than one hundred micrometers) and force (more than ten millinewtons). However, SMA materials are difficult to control because of their strong nonlinearity compared to piezoelectric materials. Electrostatic microt gripper that is capable of manipulating DNA with precision as well as biological cells have been proposed in [22, 23]. Electrostatic micro grippers able to precisely manipulate DNA and biological cells were proposed. The main advantage of electrostatic actuators is the high value of the resonance frequency which allows a high bandwidth. However the displacement range is very limited to some micrometers. Recently, electrothermal actuation has been used for design of force sensor micro grippers [24, 25].

In the second part, the importance for integration and miniaturization of micro commutator has greatly increased. To date, micro commutator have been extensively developed as radio frequency (RF) and microwave devices [26, 27] and they are typically capable to transport limited signal current on the order of tens mA. In this paper, it was proposed the design of a piezoelectric micro commutator to control industrial automation at low frequency. In particular, the device is designed to be able to carry a higher signal current compared to previous technologies. MEMS systems grant significant developments comparing to previous systems such as: giving size reduction, single chip integration feasibility, reduced power consumption and higher commutation speed if necessary. Piezoelectric actuators in the form of thin films in MEMS devices are one of the leading technologies. Among those materials that possess a perovskite structure are lead titanate solid solution (PbTiO3, PT), lead zirconate titanate (Pb(Zrx, Ti1x)O3, PZT) and lead zirconate (PbZrO3 , PZ). Currently, the piezoelectric material PZT is the most answered because of its high piezoelectric coefficients, greater than 100 µm/V, with a powerful electromechanical conversion [28]. This is an important aspect to obtain high cantilever deflections with low voltage applied actuation. Initially, the use of these types of actuators has been delayed due to integration difficulties, but in recent years considerable progress has been successfully made in this field, thus this material has been used in micro commutator, micro pumps, resonators and energy recovery systems [29-32].

2. APPROACHES TO THE DESIGN OF MICRO MANIPULATORS

2.1 Micro gripper

Our goal being to realize tasks of manipulating micro components. In addition, our research work has focused on the study of micro gripper that are simple to fabricate and which adapt to the different dimensions of the micro objects to be manipulated; therefore, piezoelectric materials as actuator is very advantageous choice because of these particular properties.

In this context, the best method used for the realization of a micromanipulator is to take the existing experiences of the design of a macromanipulator. A micro gripper can then be produced by miniaturizing macro tools to allow manipulation of small objects (figure 1). However the development of these specific organs for the process of micro assembly.

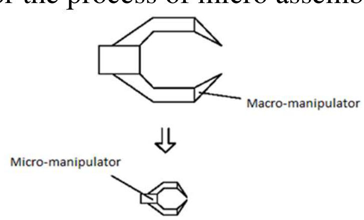

Fig. 1. Miniaturization of macro manipulators.

Generally, this process is final during the design of micro systems. It is based on the "pick-and-place" principle (figure 2). It requires at least one micromanipulator which allows with or without contact to seize, transport and set down micro objects.

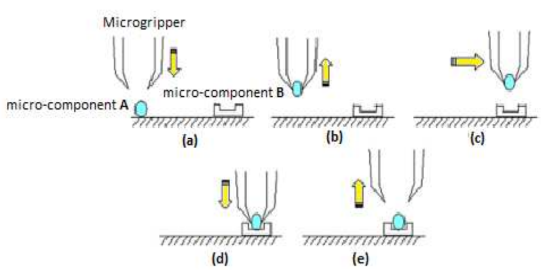

Fig. 2. Different phases of micro-assembly.

Unfortunately, all the traditional techniques used today are very expensive and present many problems of precision when picking up, holding and placing specific objects. In addition, the forces applied during the seizure of micro objects sometimes cause deformations of the micro objects to be seized or make them easily during movement from one point to another (figure 2).That is why, it is necessary to take into account the existing development in production ensuring productivity, flexibility and precision. We are talking here about micro systems which consist of a bimorph structure (two micro piezoelectric beams). These micro beams will take into consideration the properties of the micro components to perform the different handling tasks. They must also be well organized to give better productivity, especially in the context of medium and small series.

This approach consists of the manufacture and control of a finger of the micro gripper which can be deformed in flexion or laterally. Therefore, a micromanipulator can be made using two or more fingers. This concept is particularly important for the various manipulation applications requiring the possibility of actuating each finger independently of the other. The simplest method for handling micro components is represented in using a piezoelectric bimorph beam in the form of micro gripper with two fingers gripper. This can consist in its simplest form of two embedded-free beams that can move in bending (Figure 3).

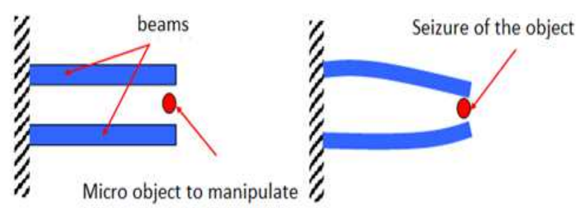

Fig. 3. Structure of a two-finger gripper.

Handling or more particularly seizing of the micro objects is easier if the extremities of the beams remain parallel to each other. Also avoiding sudden displacements of leak of the micro object. This leads to the configuration illustrated in Figure 4.

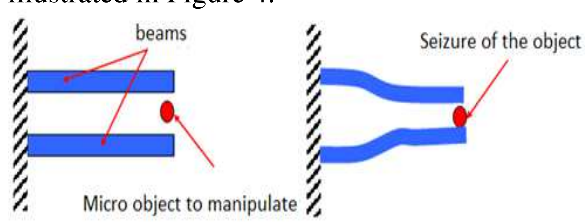

Fig. 4. Gripper with parallel extremities.

In fact, the replacement of micromanipulator is sometimes necessary according to the form and the dimensions of the micro objects during their manipulations. However, it seems expensive due to the manufacturing complexity of micromanipulators. So, we insert components placed at the extremities of the beams called extremities devices. These terminal organs have several forms depending on the micro objects to be manipulated [33, 34]. In figure 5a, different shapes of terminal devices adapted for different shapes of micro-objects have been shown. Figure 5b shows a micro gripper with a terminal device [35] which allows the seizure and transport of a micro object without destroying it.

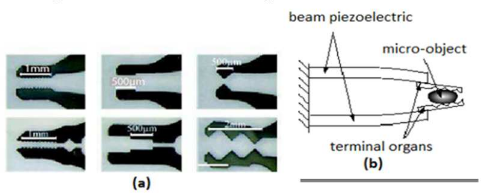

Fig. 5. Placement of terminal organs on a micro-gripper (a). (b) Example of terminal organs [36].

2.2 Electromechanical modeling of a micro gripper

The piezoelectric material consists of two micro beams with opposite polarity to each other. According to the indirect effect of this type of material, the application of an electric voltage transversely to the thickness induces a deformation in the form of deflection inside the piezoelectric layer of each micro beam, this deformation leads to the control force on the micro object. The geometry of the system is shown in figure 6.

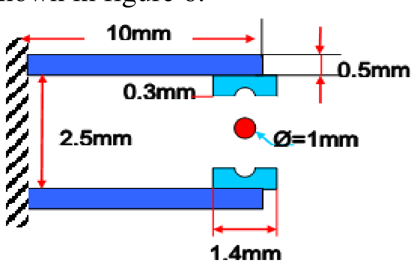

Fig. 6. Dimensions of the micro-gripper.

Knowing that there are three operating modes of piezoelectric actuators, the most commonly used are: d31 and d33. They are distinguished from each other by the direction of the electric voltage and the direction of input deformation. In the d31 mode, the two arrows are perpendicular. On the other hand in the d33 mode, they are parallel. The principle diagram of this work indicates that the mode of operation used is the d31, in which the resulting deformation forces the piezoelectric film to contract as well as the micro cantilever to bend. This work focuses on the comparison of two different manufacturing processes. The material chosen for our application is the piezoelectric ceramic PZT-5A. The principal physical characteristics of this material are listed in Table 1, and it is commonly used in the manufacture of piezoelectric actuators.

Table 1

Characteristics of piezoelectric material PZT-5A.

Young's modulus E [N.m^{-2}]	**Density ρ [Kg.m^{-3}]**	**piézoélectric Coefficient d_{31} [mV^{-1}]**
6.9x10^{10}	7700	-179x10^{-12}

Based on this motivation, this article presents the use of the finite element method (FEM) to solve the different piezoelectric complexities and their applications to the design of piezoelectric actuators. In this framework, the implementation of the finite element method is based on the standard nodal approach which was developed for piezoelectric materials by adopting three dimensional tetrahedral and hexahedral elements. The micro gripper is subjected to unit electrical voltage V applied to the terminals of the electrodes. The static deflection at the different nodes is calculated by the finite element model presented in figure 7.

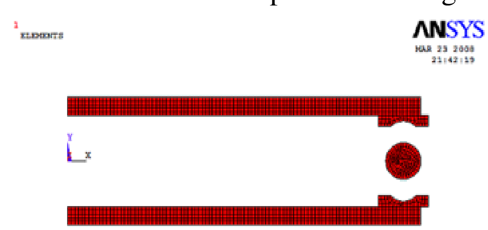

Fig. 7. Finite element model of the micro-gripper.

We carried out numerical simulations with the numerical code Ansys® in order to determine the value of the displacement due to the application of the electric field. The micro object to be grasped is a steel ball 1mm in diameter. The application of an electric field on the piezoelectric components of the micro gripper causes a deformation shown in figure 8.

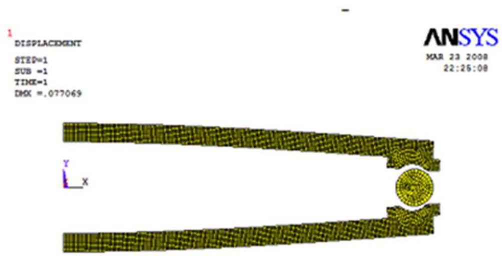

Fig. 8. Deformation of a micro-gripper under an electric field of 100V.

The results extracted from these modelings in terms of the displacement isovalues Uy and of the Von mise constraints are presented in figure 9. These simulations show that for an electric field value of 100V, the deformation obtained on the micro gripper is approximately 76µm. The maximum deformation zone coincides with the position of the object to be carried located on the end of the multilayer bar.

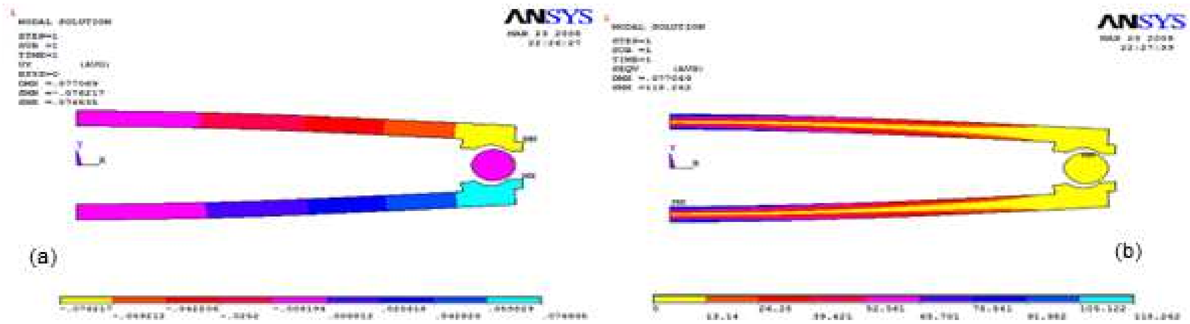

Fig. 9. Isovalues of displacements and Von mises constraints placed in a micro gripper.

3. APPROACHES FOR DESIGNING A MICRO COMMUTATOR

3.1 Micro commutator MEMS

Generally a commutator has two states: the first on state which ensures the passage of the signal, it presents a short circuit (zero impedance). The second blocked state, no signal transmission, in this case the commutator appears as an open circuit (infinite impedance). MEMS micro commutators generally consist of a mobile or mechanically deformable structure just like variable capacitors. There are two main families of MEMS micro commutators of the micro beam type: the first family is commutators with lateral contact (see figure 10a) and the second one is commutators with central contact (see figure 10b).

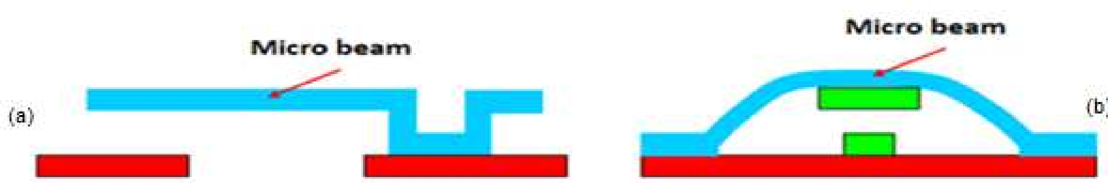

Fig. 10. Configuration of micro commutator based on a micro beam with (a) lateral contact (b) central contact.

These MEMS micro commutators are composed of a thin deformable beam. The application of an external solicitation on the micro beam generates after deflection the contact with the electrode generally arranged on the surface of the substrate. Thus, the position of the micro beam designates the on or blocked state of the micro commutator (see figure 11).

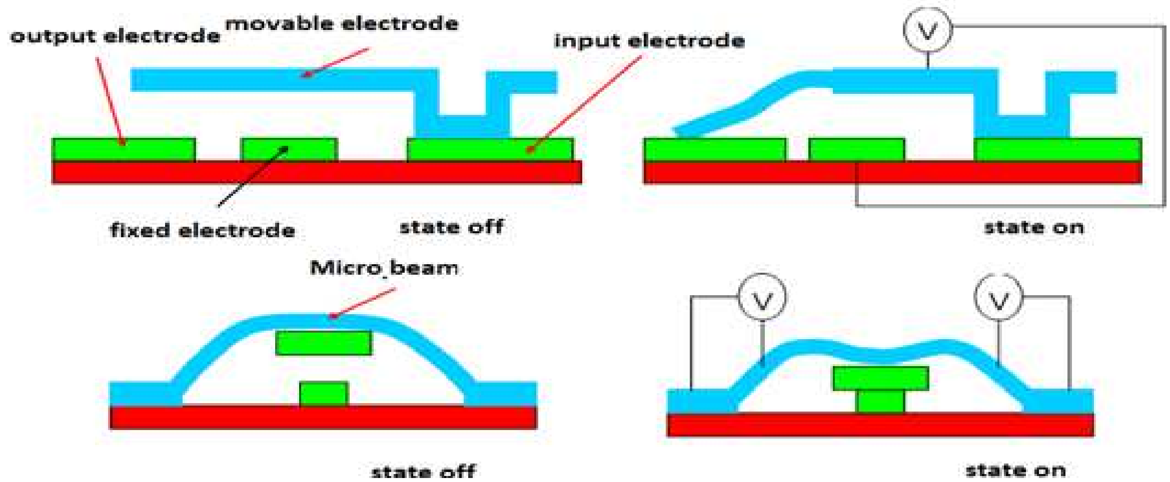

Fig. 11. Implementation of a MEMS micro-commutator based on a PZT micro-beam.

The piezoelectric polarization tensions are generally on the order of a few volts and the magnitude of the deflection contributed on the structure depends on the thickness of the piezoelectric material and its characteristics. Dilation of the piezoelectric layer is progressive with increasing actuation tension; the deflection of the micro-beam can be continuous. By reversing the polarity of the tension applied to the layer, it retracts, thus forcing the micro-beam to return to its initial position.

3.2 Electromechanical modeling of the micro commutator

First, we consider a micro commutator in the form of cantilever type micro beam, this micro beam is kept fixed at one of its extremities, but the other extremity is free for vertical movement (see figure 12a). The second modeling of a micro commutator in the form of micro beam held immobile at both extremities (see figure 12b). The cantilever will be suspended above an actuating electrode attached to the substrate. This electrode will deform the micro-beam until its movable extremity touches the contact electrode.

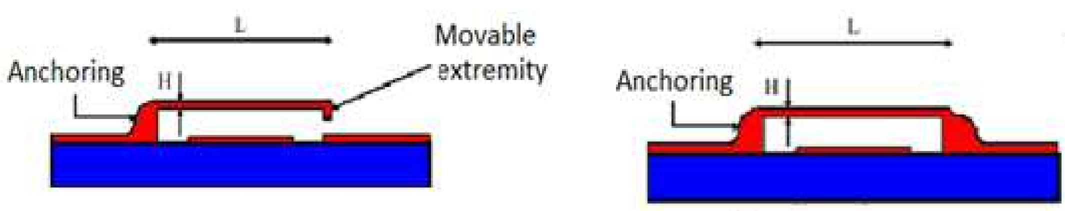

Fig. 12. Micro-commutator of length L, width W, thickness H and raised by distance h from the substrate.

The micro commutator is composed of different materials, aluminum is used for the basic structure and piezoelectric ceramic type PZT-5A for the micro beams. The properties of the PZT-5A type piezoelectric ceramic are presented in Table 1. On this effect our study is based on the cantilever structure called embedded-free beam and the bridge structure called bi-embedded beam (see figure 12 a and b). The micro beams is the section rectangular, length L, width W and thickness H. As a first approximate consideration, the electrostatic force is supposed to a localized force applied: at the free extremity in the first case of the cantilever and in the center in the second case of the bridge. Figure 13 shows the mesh of the two forms of micro commutator.

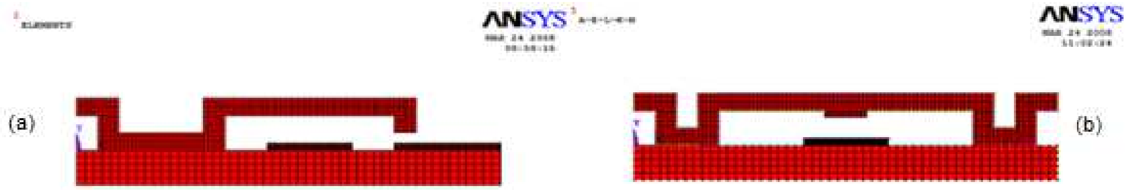

Fig. 13. Mesh of micro beams (a) and micro bridges (b).

Figure 14 shows the deformations obtained with the finite element model at two different times during a static analysis of the first micro commutator (see Figure 12a). These results in terms of displacement isovalues are obtained for an applied voltage of 100V. The deformations are obtained for an embedding length l = 10mm and a thickness H = 0.5mm. We note positively, the maximum deflection of 100µm is well located at the free extremity of the structure. In addition, it can be concluded that the deformation of the structure is very adequate with the good operation of the micro commutator.

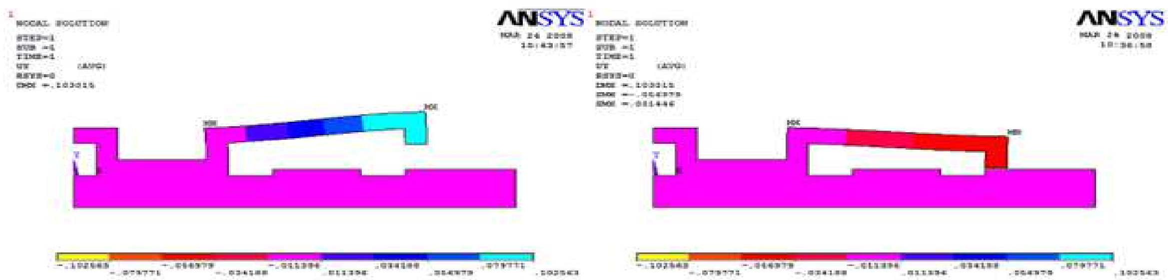

Fig. 14. Finite element simulation of the deflection of cantilever beam at tension of 100V.

Figure 15 shows the Von mises constraint values in all point of the cantilever type beam. We therefore consider the case of a bi-embedded beam (see figure 12b) with the same approach presented above, where the maximum deflection is located at the center of the beam.

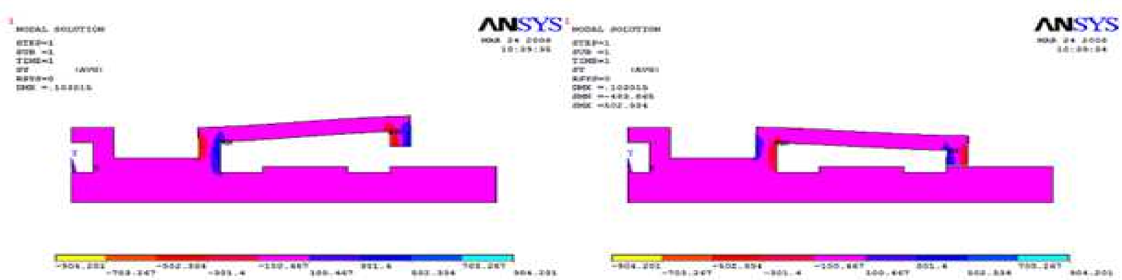

Fig. 15. Isovaleurs de contraintes de Von mises d’une cantilever.

The physical characteristics of the beam are similar with l=20mm. In figure 16, the presented results of the numerical simulation show values of order of different magnitude due to micro displacement of value 0.1µm at the center of the structure.

In figure 17, at any point of the bridge type micro commutator, the Von stress values placed under a voltage of 100V have been presented.

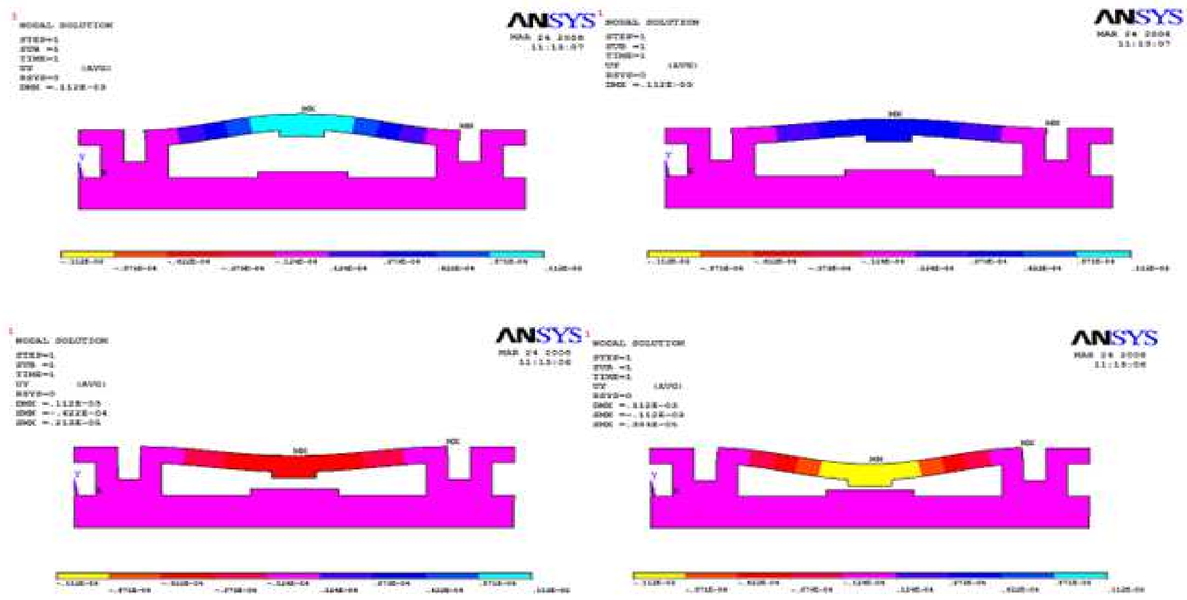

Fig. 16. Finite element simulation of the deflection of bridge under the action of tension of 100V.

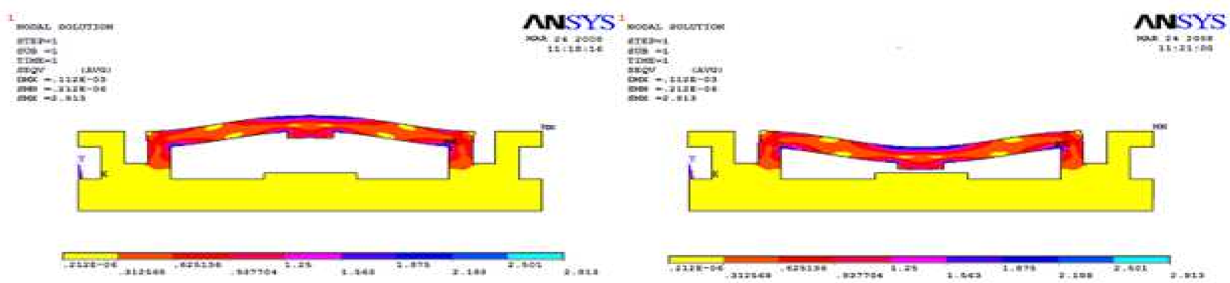

Fig. 17. Isovalues of von mise constraints of a bridge.

4. CONCLUSION AND FUTURE WORKS

The work presented in this article concerned the study of finite element modeling of micromanipulation systems actuated by piezoelectric effect. The first application using bimorph piezoelectric beams that allow relatively important displacements to be obtained. They have very interesting characteristics to realize micro manipulation tasks. The results of the numerical simulation presented show a better estimation of the force applied to the micro components to be manipulated with precisions significantly compatible with the different types of micro manipulation. In fact, we can achieve by applying the electric field, precisions of the order of 80µm of manipulation and also of a few nanometers. These results open a very interesting broad view for the design of micromanipulations of microobjects with different physical properties. For example, figure 18 shows the use of a micro gripper for sorting micro objects.

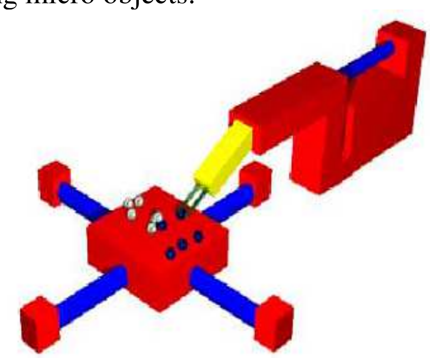

Fig. 18. Micro sorting cell.

The similar concept of the second application studied for the realization of micro commutator. We have exploited two forms of applications for micro beam type commutator, the first one with lateral contact and the second with a central contact. We carried out different numerical simulations of the models sufficiently described defined the various behaviors of the piezoelectric materials and that these types of structures can be used for other applications. Concerning the two examples of application of micro commutators, research has shown that bridge type micro beams are more robust, their electromechanical resolution is precisely lower than that of cantilever type micro beams for the same value of the applied tension. We convinced ourselves that the cantilever type micro beams showed a relative flexibility that allows them to undergo several deflections before being broken. Taking into account this observation we suggest to use in the designs of micro connection these micro beams of the cantilever type. During this paper, the results obtained are very interesting and open various perspectives. There is therefore still work to be done on these structures, particularly with regard to their designs, the choice of intelligent materials to be used and the laws of adaptable behavior as well as their realizations. Finally, this modeling could be generalized from 2D to 3D.

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SISTEME DE MICROMANIPULARE ȘI MICROSWITCH BAZATE PE MATERIALE PIEZOELECTRICE

Rezumat: În această lucrare, aplicațiile specifice dedicate microsistemelor sunt concepute pentru a efectua sarcini de micromanipulare în mod inteligent și eficient. Prima abordare propusă este un micromanipulator numit micro gripper, care este folosit pentru a manipula micro-obiecte a căror dimensiune maximă este de 1mm. Aceste dispozitive utile și uneori esențiale sunt concepute pentru a efectua operațiuni de microasamblare sau pentru a poziționa un micro obiect folosind un microscop după vizualizare. aceste microcomponente cu o precizie ridicată de mai puțin de 1 µm. A doua abordare propusă constă în două aplicații în domeniul microconexiunilor. Una dintre ele este o microgrinzi încastrate la una dintre aceste extremități și libere la cealaltă de tip cantilever. Cealaltă este o structură înglobată la cele două extremități ale tipului de pod. Aceste micro fascicule formează microcomutatorul. Scopul lucrării noastre este de a modela deviația micro-grizurilor propuse sub efectul unei solicitări externe pe baza caracteristicilor electromecanice ale materialelor piezoelectrice pentru a avea o bună manipulare a microsistemelor și o bună conexiune a microcomutatorului. Pe parcursul lucrării vor fi prezentate performanța acestor componente și pentru ce aplicații par cele mai potrivite.

Cuvinte cheie: metoda elementelor finite; actuator piezoelectric; Micromanipulare; Micro-clemă; micro comutator.

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