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Specific Aspects of Modeling and Simulation of Piezoelectric drop-on-demand Micropumps

ABSTRACT

The working principle of piezoelectric drop-on-demand micropumps represents a very complex process of coupling multiphusical effects: piezoelectricity, elasticity and multi-phase flow of immiscible fluids (liquid and gas) with the surface tension on free contact surfaces and contact angle on conact with structures. To analyze such complex coupled-field problems tools based on FEA are most convinient. The program packages ANSYS and CFDRC can handle these coupled-field analyses very efficiently. They treat coupled-field effects between different physicals fields by sequential or direct coupling analyses, in contrast to many other modeling procedures that use existing proven stand alone physical modulus for separately analyzing physical phenomena and than loosely couple the resulting mutual influence through boundary conditions which can not describe the real state.

The intention of this paper is directed to describing specific aspects of modeling and simulation of multidisciplinary physical interactions that exist in piezoelectric drop-on-demand micropumps which can be used for making verified models, defining proper simulation procedures and parameters that establish full correspondences between simulated models and real dynamical behaviour of existing micropumps.

1. INTRODUCTION

The rapid progresses in developing microsystems technology and in developing new, complex microdevices are intensely supported by a modern concept of designing new devices. That new concept is based on Computer Aided Design (CAD) combined with different numerical simulation tools. Those represent an essential key for designing and manufacturing micromechatronical devices with high performances and reliability, reduced produced costs, short development cycles and time-saving approach.

Though the concept of microdevices has been known for more than 20 years, the commercialization of microsystem technology has not progressed as fast as Integrated Circuit (IC) chip technology. The major technical barrier in developing new, revolutionary microdevices that have potential applications in medical, environmental, military and industrial applications lies in the lack of understanding physical phenomena and their interactions that occur in multiphysical microdevices. Most of them function on interactions of thermal, mechanical, electric, magnetic and/or fluidic fields. So, for making a step in advance, it is not enough to understand these areas individually, but the coupled effects of these phenomena at the same time. For that purpose CAD with numerical simulation tools have been developed to model and simulate microdevices with their interactions between different physical fields by coupled-field analyses.

A coupled-field analysis is an analysis that takes into account the interaction between two or more different disciplines of engineering. For example, a piezoelectric analysis at a piezoelectric actuator handles the interaction between structural and electric fields of a piezoelectric material. Other examples of coupled-field analyses are thermal-stress analyses for bimetallic actuators, magneto-structural analyses for electromagnetic actuators, fluid-structure analyses for fluid flow considerations and finally problems that at the same time involve complex interactions of thermal, structural and electrical fields with the fluid flow. The last type is the most complex analysis of microdevices. It is the example of the analysis of a piezo-electric micropump as an electric-structure-fluid coupled microsystem.
Currently, there are many types of micropumps used for variety of purposes. But they are mainly applied as drop-on-demand micropumps. This means that a micropump, under an electric signal given by a driving system, can eject high-speed droplets out of the nozzle with tens microns of diameter in a few microseconds. Due to high reliability, high stability, long life, high firing speed and the applicability for many kinds of liquid, the piezoelectric micropumps provide much potential for variety of applications. These advantages together with ejecting precise and uniform droplets, accurately putting droplets on specified positions, different operating conditions, batch microfabrication and so on, are the reason to take into consideration modeling complex coupled-field physical effects of a piezo-electric micropump as one of the most complex multi-disciplinary micro-electro-mechanical-system.

2. MODELING AND SIMULATION OF PIEZOELECTRIC DROP-ON-DEMAND MICROPUMPS

The working principle of a piezoelectric micropump represents a very complicated process of coupling piezoelectricity, elasticity and multi-phase flow of immiscible fluids (liquid and gas) with the surface tension on their free contact surface. To analyze such complex coupled-field problems tools based on FEA are most convenient. The program packages ANSYS and CFDRC can handle these coupled-field analyses very efficiently. They treat coupled-field effects between different physical fields by sequential or direct coupling analyses, in contrast to other modeling procedures that use existing proven stand alone physical modulus for separately analyzing physical phenomena and than loosely couple the resulting reciprocal influence through boundary conditions which can not describe the real state.
The specific aspects of modelling and simulation of a multuphysical piezoelectrical micropump including forming of a drop at the output of its nozzle can be analyzed by dividing the whole problem in a few parts. According to this approach, forming single segments of a model and defining simulation procedures and suitable parameters that are necessary in single modeling phases, with multuphysical effects that derive from different physical fields but which can be analyzed simultaneously by means of a proper coupled analysis, will be shown in this paper on an example of a piezoelectrical drop-on-demand micropump developed at the Institute for Microsystems technologies, Technical University Ilmenau, Germany. The structure of the pump is shown on Fig. 1 without the tank and supplying channel whose dimensions and shapes do not affect the working function. Towards types of entry energies, physical domains and reciprocal interactions of their effects a multiphysical analysis of the considered pump can be performed through three coupled analyses schematically represented on Fig 2.
The first analysis represents a model of a piezoelectric actuator which generates moving of a glass membrane which limits the working chamber from the top side. A static direct coupled analysis is used for the simulation of its electric and mechanical characteristics in the absence of loads from the fluid in the chamber. In the next step, the dynamic character is added to the existing model of the piezoelectric actuator, as well as a model of a fluid part with its effects. Then, a transient sequential analysis of the interaction of the working fluid and the glass structure is used. Finally, to the previously analyzed model a coupled analysis of the development of the free contact surface on the

border between fluid and gas phases by volume of fluid tracking, together with the effect of the surface tension and the contact angle, that are very important for the purpose of defining conditions for the forming of droplets, is added.

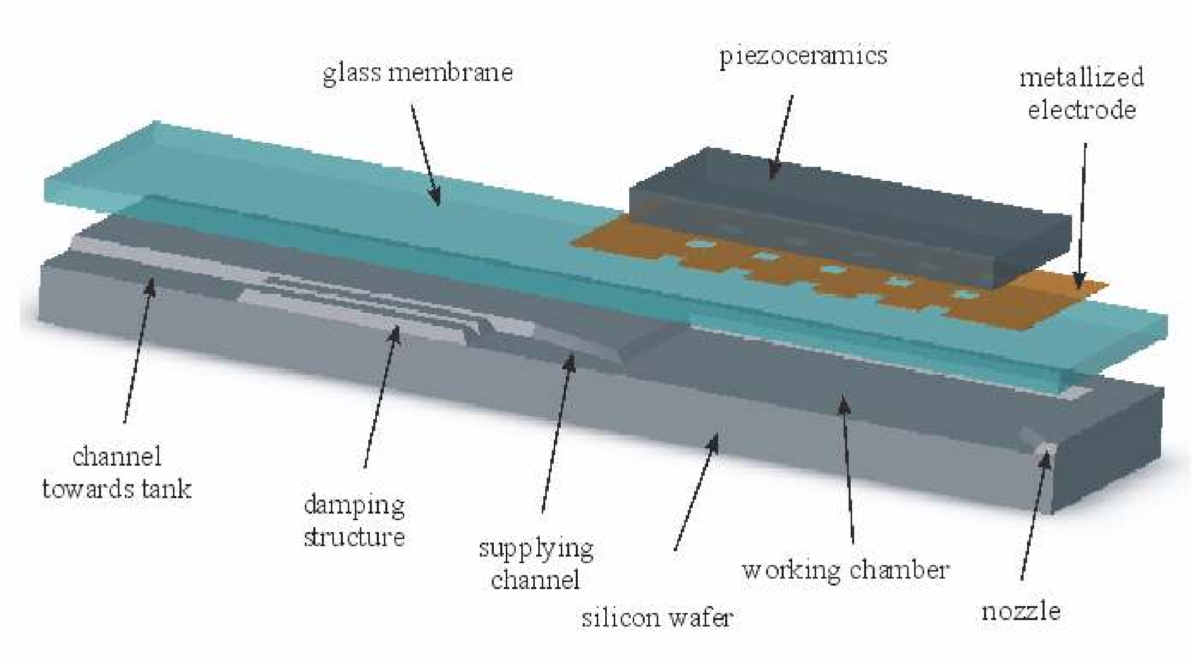


Fig. 1 Symmetrical part of the piezoelectric drop-on-demand micropump

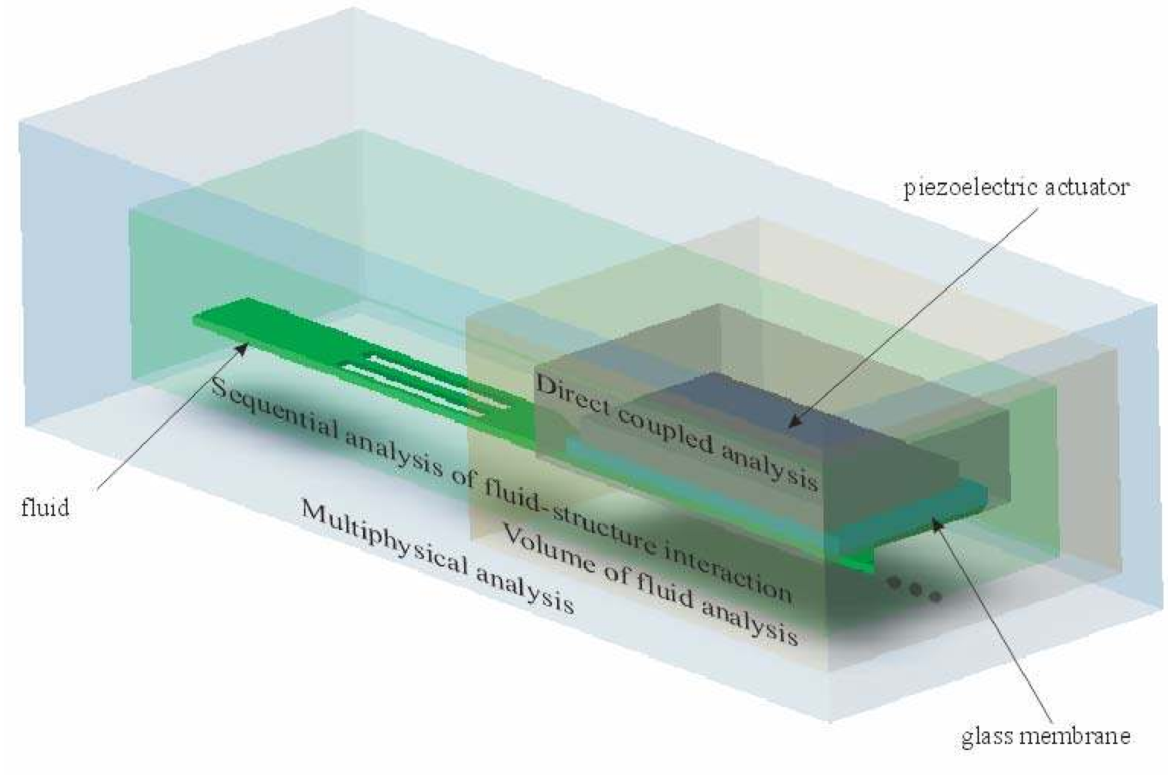


Fig. 2 Coupled analyses of the piezoelectric drop-on-demand micropump

2.1. MODELING AND SIMULATION BY DIRECT COUPLED ANALYSIS

The most influential part of the micropump structure on the process of droplets forming presents the actuator with its characteristics. Therefore, on the beginning of the modeling of multiphysical effects of the piezoelectric micropump the modeling of interaction of effects which derive at the same time from electric and mechanical fields of the piezoelectric actuator in conditions where there is no contact with the working fluid, or the fluid is with an exceptionally small density is done. In that way, as the consequence of the existing piezoelectric effect, the deflection of the glass membrane which is linearly proportional to the applied voltage is determined. Bringing the voltage on the layer of piezoelectric material generates its deformation. Because of the stiff connection with the glass membrane on which the piezoceramic material is bonded the appearance of a moment on the contact area has caused which further generates the bending of the glass membrane. As this membrane limits the chamber of the working fluid from the top side it results in changing the chamber volume and increasing or decreasing the pressure. Caused overpressure squeezes the fluid out through the nozzle in the working cycle and caused underpressure sucks the fluid through the supplying canal in the reversible cycle, realizing the pumping effect. For drop-on-demand micropumps the regular determining of the deflection of membranes at the central part is especially important, because just the quantity of the fluid squeezed out of the nozzle, influenced by the chamber volume changing, directly operates on the way of droplets forming.
For this part, models based on the finite element modeling has been set in order to achieve the correct determining of the elastic membrane deflection, in respect to analytical models that mainly neglect anisotropic natures of mechanical and dielectric characteristics of piezoceramics, do not take in the consideration coupled strains which return from the membrane to the piezoceramic layer and suppose ideal supporting conditions, which is not the case at real micropumps because of the existence of input and output channels. Moreover, simulated numerical models can consider influences of glue layers and metallized electrodes, as well as consider very complex shapes of the used piezoceramic material.
In the mentioned programs the coupled analysis of electric and mechanical properties is performed by using the direct coupled method. It represents a unique analysis based on special coupled finite elements which comprehend all necessary degrees of freedom for a concrete multiphysical analysis. Therefore, suitable coupled finite elements at the same time posses mechanical UX, UY and UZ (movements in directions of coordinate axes) and electric VOLT (voltage) degrees of freedom in each node. For the structural analysis for analyzing the deformation of the glass membrane classic finite elements which have only mechanical degrees of freedom are used. The used model has been presented on Fig. 3, with the finite element mesh, applied boundary conditions and electrodes.

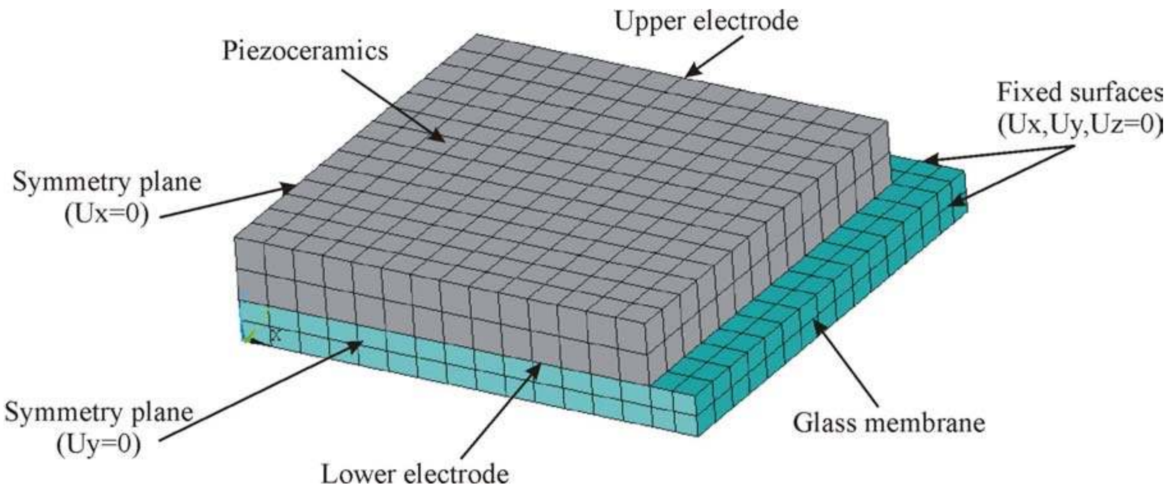


Fig. 3 The symmetrical quarter of the model of the piezoelectric actuator
(Z direction of the polarization of the piezoelectric material)

After applying the positive DC voltage on the lower electrode of the piezoelectric actuator model values for the glass membrane deflection, shown on Fig. 4, are obtained by the static direct coupled analysis, without taking into account the influence of the fluid in the chamber.

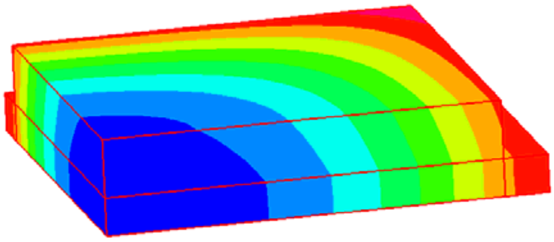


Fig. 4 Displacements of the model of the piezoelectric actuator

2.2. MODELING AND SIMULATION BY SEQUENTIAL ANALYSIS OF INTERACTION BETWEEN FLUID AND STRUCTURE

For a piezoelectric drop-on-demand micropump the dynamic behavior of a piezoelectric actuator is of the special importance, because the process of generating a droplet at a nozzle requires a determined time interval. Moreover, the deformation of a glass membrane of a piezoelectric actuator changes the volume the working chamber which causes the changing of the pressure in the chamber. That means, it is necessary to take into consideration the external load which acts from the fluid in the chamber to the membrane as the function of time, what points to the further need of dynamic modeling. Research of the dynamic behavior of a piezoelectric actuator can point out to another very important aspect in the perceiving of droplet forming conditions. It is also the function of dynamic behavior of the piezoelectric actuator system when besides just one basic droplet a lot of tiny accompanying droplets are formed. Such accompanying droplets, called satellites, obstruct the generation of the regular form of a demanded droplets. The optimization of characteristics of the oscillatory process of piezoelectric actuator moving it is able to operate the quality of droplets forming by establishing conditions which eliminate the appearance of accompanying droplets.

Therefore, for the following stage of the multiphysical analysis of a piezoelectric micropump the research of the dynamic response of a piezoelectric actuator is performed at the same time with the modeling and simulation of multiphysical effects of the interaction of the working fluid and the glass structure of a piezoelectric actuator. During this simulation the reciprocal interaction between the structure and fluid in two successive steps is taken into consideration by numerical tools of a nonlinear transient sequential analysis. In that way, results of sequential analyses of fluid and structure domains are exchanged across the given contact area determined between the fluid and structure regions. By such coupled analysis simultaneous influences of the deformation of structure to velocities of the fluid and the damping action of fluid forces to the structure in the reverse direction are considered. It is the case of a completely coupled analysis in which not only results of the previous analysis operate the next analysis, but where in the following simulation step changes on the input data of the first analysis caused as the consequences after executing the second analysis are taken into consideration.

Therefore, previously used model of a piezoelectric actuator is additionally extended by volumes filled with fluid which are to be discretized by fluid finite elements, in order to continue with using finite element methods which can, compared to analytical assumptions, enable taking into consideration the existence of a lot of physical quantities whose reciprocal effects have to be observed at the same time, couple nonlinearities which are consequences of the dynamic behavior of the structure and fluid and others complex coupled characteristics of the bidirectional interaction of influences between the fluid and elastic structure. Moreover, simulated numerical models can consider very complex and irregular structures of fluid regions which can have the most different characteristics of density and viscosity as well.

For the discretization of fluid domains at a transient fluid-structure interaction analysis finite elements are used. They have in each node degrees of freedom characteristic for the flow analysis VX, VY, VZ, PRES and TEMP (velocities in directions of coordinate axes, pressure and temperature). Also they have degrees of freedom UX, UY and UZ which provide the traction of movable boundary conditions. So, the nodal points moving of the finite elements mesh in the fluid region follows the moving of the contact area of the fluid and structure.
Modeling and simulation of multiphysical effects by using a nonlinear transient coupled sequential analysis at a drop-on-demand micropump continues with the fluid-structure interaction analysis between the glass structures of the piezoelectric actuator and the whole domain of the working fluid. For that purpose the model of the piezoelectric actuator with characteristic parameters and boundary conditions, Fig. 3, is further extended with the fluid part. The fluid domain comprises from a working chamber, a nozzle, a supplying canal, a part for with an optimally chosen structure for increasing resistance of fluid flow, which in the working cycle operates the quantity of fluid which returns in the supplying part. There exists one more chamber which can be considered as a fluid element of endless capacity and it represents a tank from which the working chamber is supplied by fluid in the reversible cycle.

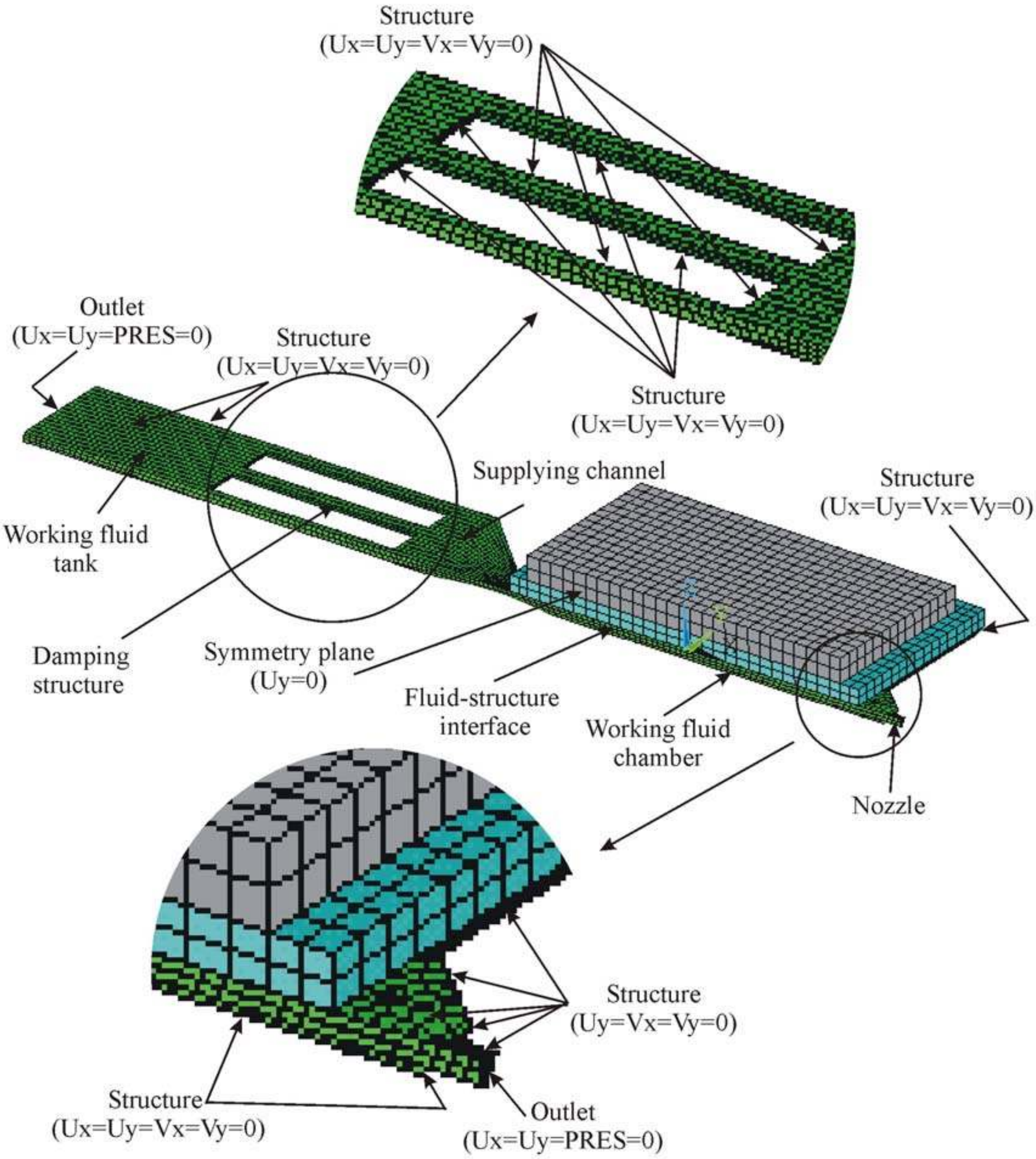


Fig. 5 The symmetrical half of the model of the piezoelectric drop-on-demand micropump

The discretized shape of the symmetrical half of the parametric model of the considered piezoelectric drop-on-demand micropump has been presented on Fig. 5, with the finite element mesh for the structural and fluid regions, the contact area of the fluid and structure and necessary boundary conditions of the fluid domain.
In order to bring the simulation of multiphysical effects of the interaction of the water as a working fluid and the glass membrane of the piezoelectric actuators closer to the real conditions of a drop-on-demand micropump functioning, it is necessary to use an actuation electric signal of the impulse shape presented on Fig. 6. For the such managing signal the following parameters are characteristic: the time t_f for achieving the maximal voltage V_{max}, the time t_c during which the voltage is maintained constant, the time t_o when the voltage declines to the value V_r and the time of relaxation t_r which is necessarily for the pump to prepare for the next pumping cycle.

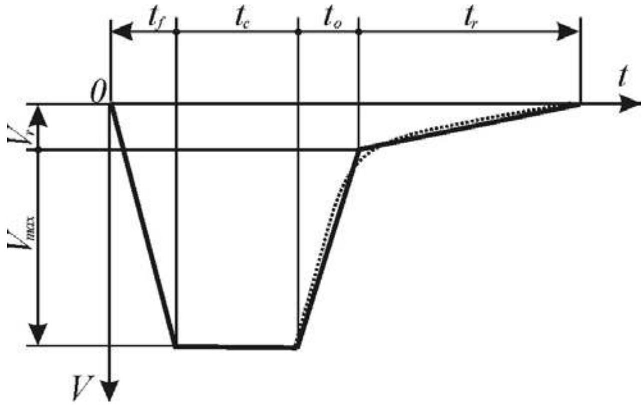
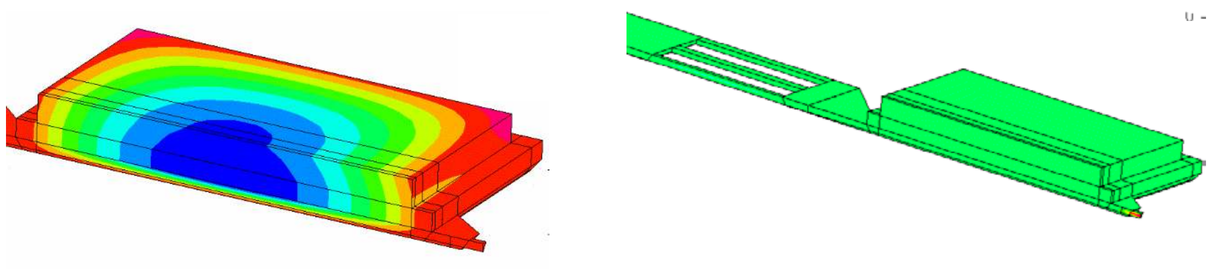


Fig. 6 The actuating impulse signal of the piezoelectric actuator of the drop-on-demand micropump

The responses of the simulation of the reciprocal influence between the glass membrane of the piezoelectric actuator and the fluid in the total region of the working fluid of the considered piezoelectric micropump are given on Fig. 7 a) and b). Their graphic presentations are given on Fig. 8 and Fig. 9.



a) Deflection of the membrane b) Velocity distribution in the fluid region

Fig. 7 The responses of the fluid-structure simulation of the model of the piezoelectric drop-on-demand micropump

From the diagram of the analysis of the dynamic response of the glass membrane deflection of the model of the piezoelectric micropump, Fig. 8, it is noticeable nonlinear establishing of the membrane steady state, its up-down movements in the period of the constant actuating impulse and the continuation of its oscillations in the part of its reversible movement to the starting position.
It is similar to the velocity diagram of the fluid that goes out through the nozzle, Fig. 9, where it can be noticed that in the part in which it is expected that the progressive membrane moving and overpressure in the chamber squeezes out the fluid all the time. Nevertheless, in some moments the

reversible movement of the fluid towards the chamber exists. Also, in the part where the membrane should rest, because of the constant voltage, together with the fluid, there are still oscillations. The same is during the reversible membrane moving when the fluid from time to time moves towards the exit, i.e. the nozzle. Such dynamic behavior of the membrane and fluid are the consequences of effects that proceed from simultaneous, reciprocal, two-way influences of the membrane pressure from the one side and the fluid damping from the other side.

The obtained shapes of the responses of structural deflections and velocities of fluid prove that the modeling of multiphysical effects at piezoelectric drop-on-demand micropumps by using the coupled analysis for analyzing interaction of the working fluid and glass membrane is completely defined by using the nonlinear transient coupled sequential analysis which takes into consideration all effects that exist by the complex interactions of fluids and structures in real conditions.

Time

Deflection

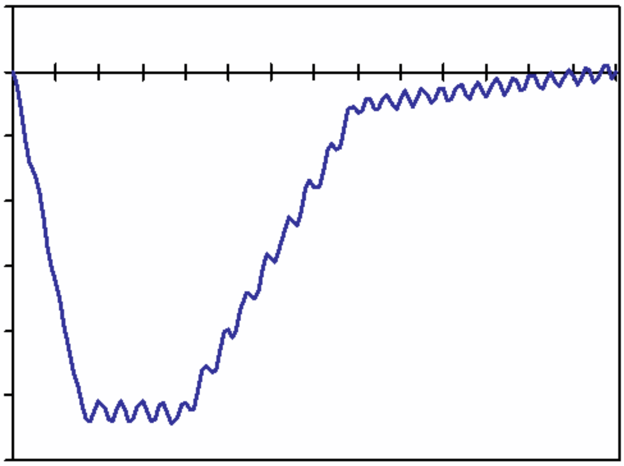


Fig. 8 Deflections of the central membrane part of the fluid-structure simulation of the model of the piezoelectric drop-on-demand micropump

Time

Velocity

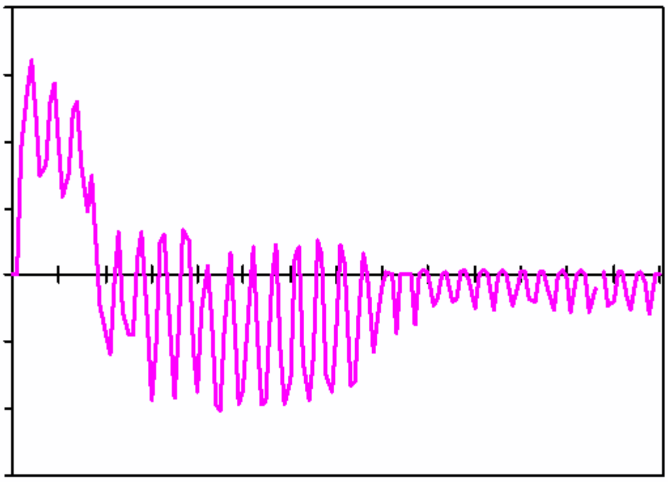


Fig. 9 Fluid velocities through the nozzle of the fluid-structure simulation of the model of the piezoelectric drop-on-demand micropump

2.3. MODELING AND SIMULATION OF DEVELOPING A FREE CONTACT SURFACE BY VOLUME OF FLUID TRACKING

By the previous fluid-structure analysis the distribution of velocities in the fluid region caused by moving of the membrane in the contact with the fluid can be obtained as one of possible results. However, some other fluid characteristic can not be noticed by such analysis. So, it is neither possible to analyze the forming of a droplet of a small quantity of viscous fluid which is free in the airspace, nor the forming of a characteristic shape when a droplet arrives in touch with a fixed surface. For the modeling and simulation of multiphysical effects, in the first case between gas and fluid, and in the second case between fluid and structure, it is necessary to consider intermolecular attractive forces between molecules inside the fluid, and adhesive forces between molecules from the surface of the fluid and the structure. This is not possible in the algorithms of the previous fluid analyses which are based on the solving of equations of classic fluid mechanics, equation of continuity and equation of conservation of momentum. For these analyses it is necessary to track the development of a free contact surface, the surface which exists on the border district of the fluid region in contact with the surrounding gas or structure, together with taking into consideration effects of the surface tension and adhesions in the contact with a fixed surface.

Analyzing of the surface tension is especially important because of its very large influence, next to the mentioned phenomena referred to droplets which also manifest in macrosystems, by the fluids in microchannels with diameters from a few micrometers to a few tenths of micrometers, especially if they have been opened at one end to the surrounding air. The existence of the surface tension in microsystems has a consequence of forming of a meniscus of the free surface in contact with the air, which prevents the fluid to go towards the open end of the channel. However, the same effect has also negative consequence when. During fluid moving towards the open end of the channel the surface tension in the combination with the friction of the fluid against contact areas of channel produces additional resistance that opposes the fluid moving. One more consequence of the surface tension is characteristic exclusively for open pipes of small cross sections. By immersing those in a fluid the effect of capillarity which causes that the fluid fills the pipe to some height without external influences.

Those are just the basic characteristics of the functioning process of piezoelectric micropumps. For the droplets forming it is firstly necessary to track the development of the free surface between the working fluid which goes out from the nozzle and the surrounding air. Then the process continues by detaching of a fluid dose of the fluid which remains in the nozzle during what a droplet is formed as the consequence of the surface tension. In addition, the process of filling of the empty space in the nozzle which remains after pumping is very important. Then, under the action of the capillary force the fluid from the working chamber slowly fills the empty nozzle, which is also the effect based on the surface tension.

On the basis of the previous the coupled analysis of the development of the free surface on the border between the fluid and gas phase by volume of fluid tracking together with the effect of the surface tension should be done as the most important multiphysical analysis for piezoelectric drop-on-demand micropumps with the purpose of defining optimal conditions for the forming droplets that leave the nozzle. The basic procedure refers to the analysis of the complex flow of more fluid components, in this case two of them, which are mutually immiscible and with a quite large difference in their densities. It is based on the algorithm which tracks the volume of the fluid by tracking movements of the parts on which the total volume of the fluid domain is divided. During this analysis, each constituent part of the volume of the fluid acquires a value from zero to one. Totally empty parts, the parts with only a gas phase, are denoted by zero, while parts totally filled by a fluid are denoted by one. Values between zero and one point to this that the suitable element is partially filled by a fluid, the second part is filled by a gas, and it represents a border element which builds a free surface between the fluid and gas domain. In order to analyze the dynamic behavior of a free surface with taking into consideration the influence of the surface tension, the previous

analyzing procedure of volume of fluid tracking have to been extended by a part in which the surface tension is modeled as a continuous surface force which is translated in a local volume force which acts in the area of the free surface.
For the purpose of the analysis of the development of the free surface of the water as a working fluid by volume of fluid tracking with taking into consideration the effect of the surface tension in the contact with the surrounding air and the adhesion in respect to contact areas with the silicon substrate and glass membrane at the considered piezoelectric micropump the symmetrical half of the model of the piezoelectric micropump presented on Fig. 5 is used. Specific qualities which characterize the new type of analysis are subsequently added to the existing model and defined simulation procedure. So, the model is expanded firstly by a discretized domain filled with the air in which the water is pumping. In that case the starting model is extended by a new district with very fine finite element mesh which considerably increases the total amount of finite elements. Because of a recommendation that the number of finite elements in an analysis for tracking transferring of volume of fluid should be as small as possible for the analysis of tracking free surface development of volume of fluid that goes out from the nozzle some parts of fluid regions can be neglected in the process of modeling and simulation. These are districts of supplying canal, damping structures and canal which leads to the chamber of the tank. At the previous model these parts are excluded but their influences are replaced by the changeable pressure which acts on the entrance of the working chamber.

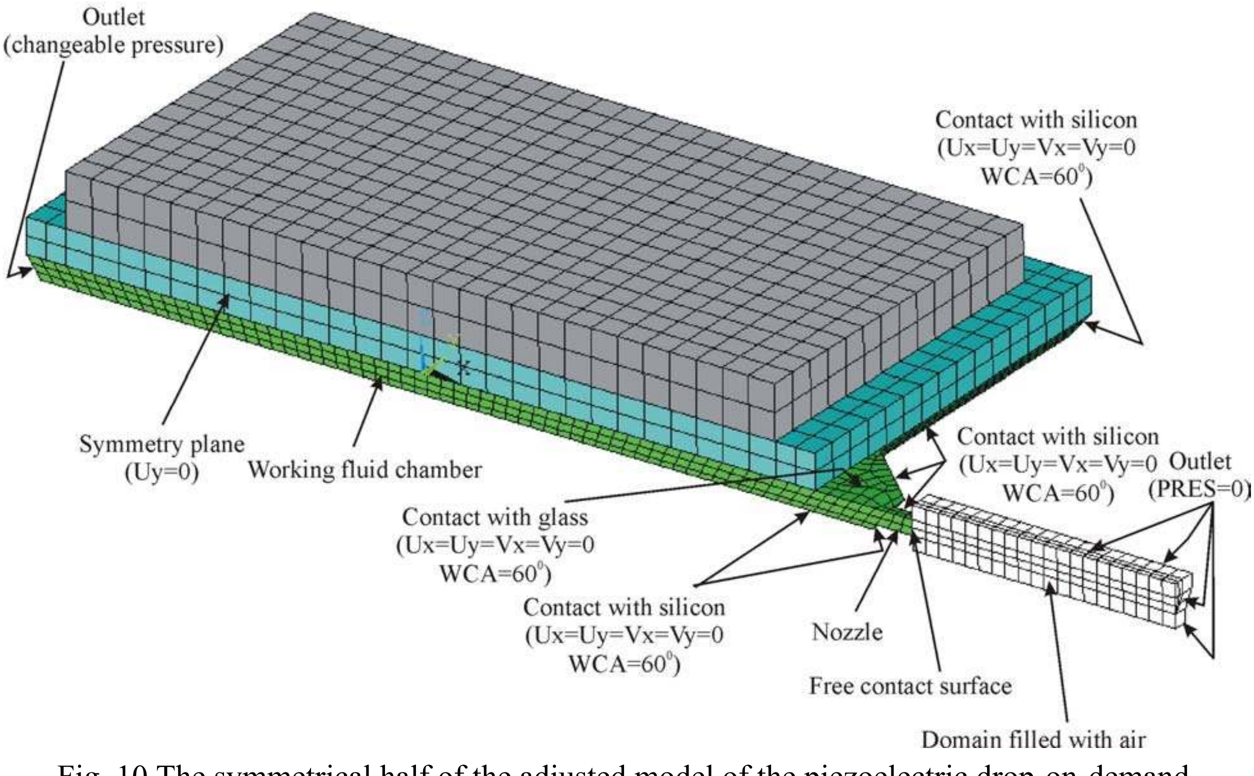


Fig. 10 The symmetrical half of the adjusted model of the piezoelectric drop-on-demand micropump

In this way an adjusted model is obtained which comprises from a piezoelectric actuator, working chamber, nozzle and a part filled with the air, as it is shown on Fig. 10. The model is adjusted for the analysis of development of the free surface by volume of fluid tracking together with effects of the surface tension and adhesion. Next to already used boundary conditions in the fluid, the additional boundary conditions characteristic for the new type of the analysis are presented on Fig. 10 for the symmetrical half of the adjusted model of the piezoelectric drop-on-demand micropump. The most significant additional condition refers to the starting distribution of the volume of fluid.

Than, it is defined which parts of the volume of fluid are completely filled by fluid, or are empty, in other words filled by air. In that way the position of the free surface, as a natural border between the fluid and air districts is set. Ambient conditions are defined in the district filled by the air in which the water goes out. On faces of contacts with silicon and glass substrates, next to other characteristics of boundary conditions which are used in order to define a contact with fixed surface, the value of contact angle is set as well. For that purpose the value of contact angle of 60^0 is used that corresponds to a contact between the water and the silicon or glass.

The extended simulation procedure for the tracking of development of the free surface on the border between the fluid and air, next to so far used physical characteristics of density and viscosity of the water as the working fluid, additionally requires defining of the value of its surface tension, as well as the physical characteristics of the air which fills the district where the working fluid is pumped. For the realization of the final simulation of the analysis of the development of the free surface by volume of fluid tracking together with taking into consideration the surface tension and contact angle for the purpose of analyzing of forming droplets in a determined moment at the considered piezoelectric micropump a specific simulation procedure is used. It begins with the execution of the analysis of influences of multiphysical effects at the model of the piezoelectric micropump with the total fluid region from Fig. 5, but with those conditions which are characteristic for the final simulation. In this way the pressure distribution which replaces influences of a part of the supplying canal, damping structures and the canal which leads towards the tank, which are excluded at the adapted model on Fig. 10, is obtained.

With all the required data at disposal the final simulation of the analysis of development of the free surface by volume of fluid tracking together with taking into consideration the surface tension and contact angle is performed for the purpose of the analysis of forming of a droplet in the determined moment, on the symmetrical half of the adjusted model of the piezoelectric drop-on-demand micropump from Fig. 10. A result of a such simulation can be a droplet presented on Fig. 11. For this case, the suggested procedure has to be performed just with optimal values of influential parameters of voltage and frequency of the initiating impulse signal coordinated with other influential parameters of geometric characteristics of analyzed structures of the fluid district and piezoelectric actuators, as well as physical characteristics of used materials water, glass and piezoceramics. Only then the suitable optimal combination of values of influential parameters is obtained which provides conditions that in the moment when the reflexive membrane movement starts the quantity of the fluid pumped out from the nozzle of the piezoelectric micropump model forms a droplet of a regular shape and determined speed. In other cases, by other combinations of values of influential parameters, the quantity of the fluid which appears at the outlet of the nozzle can come back in the nozzle without forming a droplet, go in the form of a jet or form more droplets one by one or at the same time.

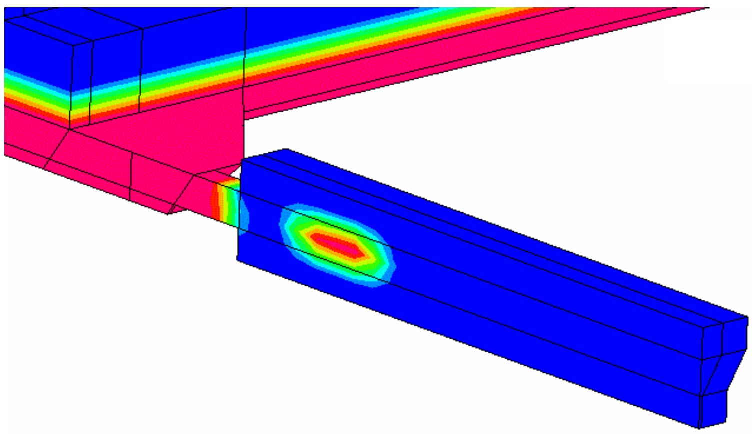


Fig. 11 A droplet formed by the suggested simulation procedure on the symmetrical half of the adjusted model of the piezoelectric drop-on-demand micropump

The process of a droplet forming at the considered piezoelectric micropump begins by bringing an initiating impulse signal on electrodes of the piezoelectric actuator, with the starting position of the free surface on the opening of the nozzle Fig. 12 a), when the membrane of the working chamber starts moving. Then, the volume of the chamber of the working fluid decreases and the pressure in the chamber increases. Those result in pushing the working fluid through the opening of the nozzle in the district filled with the air. In the contact with the air, because of the surface tension, the squeezed fluid starts forming the characteristic shape of the convex meniscus Fig. 12 b). Before long the cylindrical continuation of meniscus up to the opening of the nozzle is formed Fig. 12 c). After this the narrowing of this cylindrical part begins Fig. 12 d), which continues Fig. 12 e) to the moment of complete breaking and a droplet forming Fig. 12 f). The droplet moves further under the inertia. The fluid left in the nozzle, during the reversible membrane moving, returns through the nozzle towards the chamber forming again the meniscus of the free surface but this time with a concave shape Fig. 12 g). In the period of the micropump relaxation the free surface continues to oscillate inside the nozzle changing its shape Fig. 12 h), while finally the fluid from the working chamber fills the empty part of the nozzle under the action of capillary forces. Finally, the free surface is again at the opening of the nozzle and the considered piezoelectric micropump is ready for the new pumping cycle Fig. 12 i).

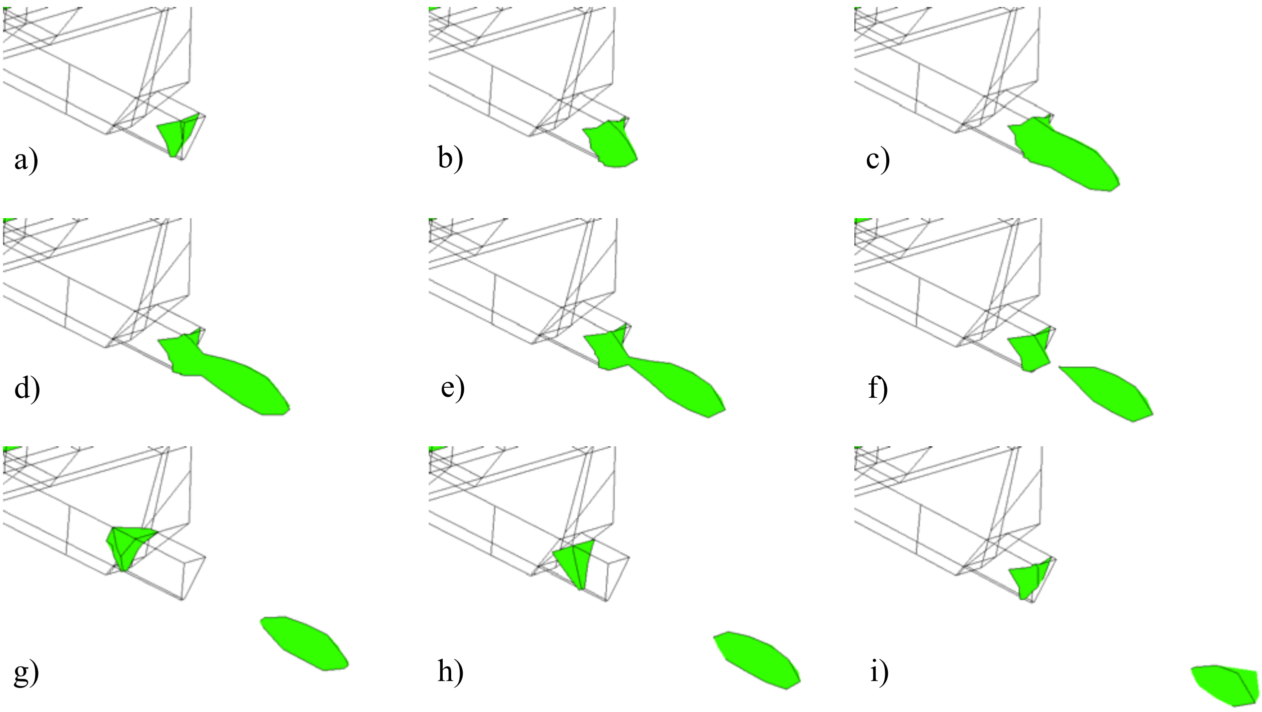


Fig. 12 Developing of the free surface during the suggested simulation procedure of a droplet forming on the symmetrical half of the adjusted model of the piezoelectric drop-on-demand micropump
(Note: on these figures the planar symmetry of the model is used for showing the both symmetrical halves of the free surface)

3. CONCLUSION

The main intention of the paper is describing specific aspects of modeling and simulation of multidisciplinary physical interactions that exist in piezoelectric drop-on-demand micropumps. For that purpose the interaction between structural and electrical physical fields is coupled by a direct coupling method. In this way caused actuating displacements of a piezoelectric material are calculated due to the applied voltage. The transient fluid-structure interaction is the next coupled-field problem that are taken into account. For this purpose the fluid-solid sequential coupling analysis is predicted. It allows the fluid-solid interaction between finite elements in the fluid and structural region. The additional very important problem in the simulation of droplets leaving a nozzle is to track the free contact surface between the immiscible fluids which have the quite large difference in their densities. This is taken into account with a numerical method for multi-phase fluid flow modeling which considers effects of the surface tension and contact angle by volume of fluid tracking.

The most important aspect of the proposed concept is that the physically based piezoelectric micropump model, obtained in this way, could be further used for finding optimized parameters for any variety of different technological or economical demands, including necessary firing speed, geometry and behaviour of droplets, possibility for application different kinds of fluid (including ink, water, oil, solvent, wax, polymers, solder, chemicals, body liquids, medicines and many other liquids) and so on.

The practical contribution would be giving useful hints and instructions to piezoelectrical micropump designers on important development questions: optimal geometrical parameters, nozzle shape, applied voltage, fluid loss, refill time, immunity on temperature variations, droplet velocity, secondary droplets forming and so on, that can help them for quickly and efficiently satisfying different market demands.

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