Applying the Golden Section Search in Optimization of Micro actuator Design

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Abstract - **The article presents the results of the application of golden section search for selection of the MEMS electro-actuator comb length to receive the desired displacement at given voltage heating. The proposed solutions have been implemented programmatically using the ANSYS system.**

Keywords - **computer-aided design, MEMS, electro-actuator, finite element method, golden section search, Bisection method.**

I. Introduction

Solid materials are sensitive to the temperature changes. They have a tendency to get smaller or larger, depending on what we call thermal expansion. This property is used in MEMS devices design to actuate a device [1-4]. MEMS thermo-electric micro actuators [5, 6] producing linear motion on temperature change in accordance with Lenz-Joule law have recently attracted deserved attention from industry and scientists [7-10]. The dimensions of these MEMS devices can have several micrometers and being produced mostly of polysilicon. Micro electric actuators are mainly used for positioning of micro-mirrors or to move micro devices. To ramp up the effective force multiple actuators can be combined together.

The main goal of the conducted analysis was to calculate the actuator spike deflection depending on the voltage applied to the contact areas (application of golden section search for selection of the MEMS electro-actuator comb length to receive the desired displacement at given voltage heating).

It is knowns, that while designing electric actuators, engineers are facing tasks to make a structure that would ensure the necessary deflection for a given voltage. Scientists spend a lot of time to optimize the design in order to obtain optimal output characteristics. There are many known ways to optimize such design. One of these methods is genetic algorithms, an example of which can be found in [10]. However, most optimization techniques cannot be applied to tackle the issues that can only be solved by finite element method. The analysis has been conducted to choose the optimization techniques to be applied in the ANSYS system. The received results backed the decisions that to calculate the length of the micro actuator comb allowing to get the desired bias voltage for a given heat one needs to use the golden section search [12].We made a decision develop both an algorithm allowing to set the desired length of comb using the golden section search and the software to implement the proposed solution. That has made it possible to automate the research process using the ANSYS system.

II. The Principle of Work and Design

A number of thermal-electrical actuators have been investigated both analytically and experimentally. Traditional thermal actuators are electrically driven. MEMS thermal-electric actuator is based on thermal expansion between a thin beam and a plate. The potential difference applied to the electrical contact areas induces the current flow between them. Polysilicon constitutes a resistance to the current, which causes the Joule heating. It should be stated that the resistance of a thin beam is larger than that of the plate. Thus, the thin beam heats up to higher temperature than the plate which results in bending the spike into the side of the plate. The maximum deformation occurs at the end of the structure. The value is a function of spike deflection directly proportional to the potential difference. Thus, the deviation of the spike can be accurately calibrated depending on the applied voltage. The design of an actuator and example of substitution for 0,2 μm, which we wanted to achieve is presented in Fig.1.

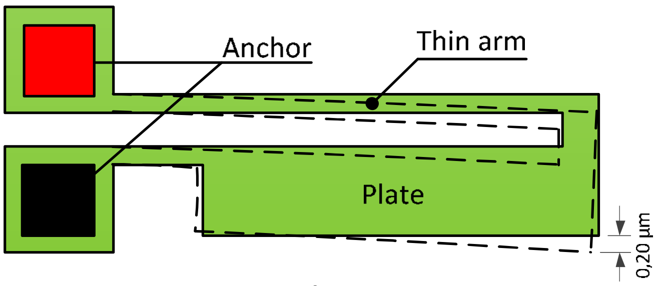

Fig. 1 Design of electrical actuator.

III. Automating the Calculation of Maximum Displacement

To automate the process of micro actuator design optimization, firstly, there is a need to develop a code for the ANSYS system allowing to determine the offset for the given design parameter constants. Examples of the code for the ANSYS system are shown in Fig. 2. The program defines all parameters, which are read from the file named parametr.txt, except L2 value which is the length of the micro actuator comb, as presented in Fig. 1. The program builds geometry, detects material properties [13], creates the finite element mesh, detects the specified boundary conditions and, finally, sets the MUSUM variable to the maximum displacement of the micro actuator comb. Other variables can be retrieved from parametr.txt file similarly to L2. For example, one can change length and thickness at the same time.

The result of the program (Fig. 2) is the distribution of strains in the actuator plate, and strain distribution images are automatically saved into the working folder.

IV. USING THE GOLD SECTION SEARCH TO OPTIMIZE MICRO ACTUATOR

The algorithm of the golden section search [12] is similar to the half-division method, the only difference is that the division of the segment is calculated based on the golden ratio (Fig. 2.):

$$x_{mid} = a + 0.618(b - a) \tag{1}$$

The effectiveness of this method is greater than the half-division method and can be estimated as:

$$E = (0.618)^{1-n} \tag{2}$$

where n is a number of equation calculation. Therefore it was decided to use this method.

The most often used condition of termination of the iterative process is:

$$|x_{n+1} - x_n| \le \varepsilon \tag{3}$$

where ε is a defined error.

In Fig. 4 we presented a flow diagram of the proposed optimization algorithm of the micro actuator design using the golden section search, where:

L2 – length of micro actuator comb;
Accur – accuracy to be achieved;
DSPL – displacement to be obtained;
a,b – minimum and maximum length of the micro actuator comb;
USUM – displacement obtained at the current step;
aUSUM, bUSUM i xUSUM - displacement obtained at the current step assuming L2=a, L2=b and L2=x, respectively.

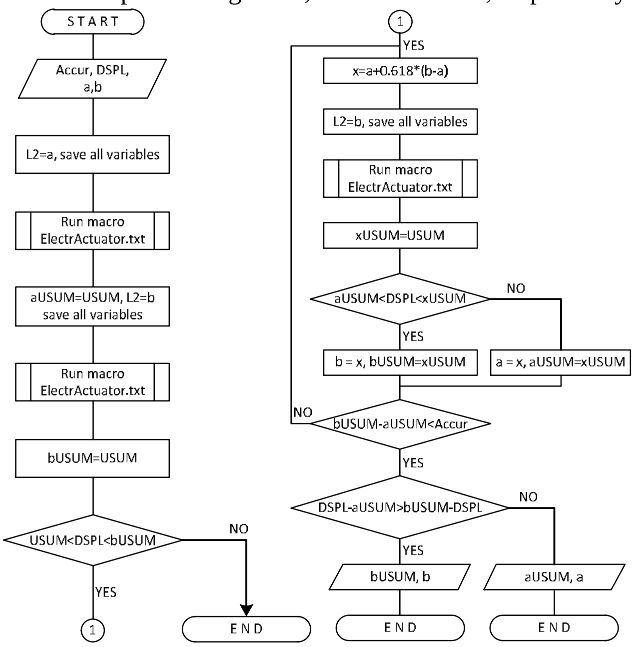

Fig. 4. The flow diagram of algorithm for automated selection of actuator parameters.

```
/units, uMKS
Accur=0.01        ! Accuracy um
DSPL=0.20         ! Displacement Desired value movement
a1=300            ! Initial value l2
b1=600            ! Final value l2
l2=a
PARSAV,SCALAR,'Parametr','txt',' '
/INPUT,'ElectrActuator','txt','C:\_Termoactuator1\',, 0
aUSUM=MUSUM
l2=b
PARSAV,SCALAR,'Parametr','txt',' '
/INPUT,'ElectrActuator','txt','C:\_Termoactuator1\',, 0
bUSUM=MUSUM
*IF,DSPL,GT,aUSUM,AND,DSPL,LT,bUSUM,THEN
  ! DSPL>aUSUM and DSPL<bUSUM
 :LABEL1
  x=a+0.618*(b1-a1)
  l2=x
  PARSAV,SCALAR,'Parametr','txt',' '
  /INPUT,'ElectrActuator','txt','C:\_Termoactuator1\',, 0
  xUSUM=MUSUM
 *ENDIF
 *IF,DSPL,GT,aUSUM,AND,DSPL,LT,xUSUM,THEN
   b=x
   bUSUM=xUSUM
 *ELSE
   a=x
   aUSUM=xUSUM
 *ENDIF
 *IF,bUSUM-aUSUM,LT,Accur,THEN
    *GO,:LABEL1
 *ENDIF
  *IF,DSPL-aUSUM,GT,bUSUM-DSPL,THEN
         *CFOPEN,Result,txt,C:\_Termoactuator1\,
         *VWRITE,bUSUM,b
(2F8.3)
         *CFCLOS
  *ELSE
         *CFOPEN,Result,txt,C:\_Termoactuator1\,
         *VWRITE,aUSUM,a
(2F8.3)
         *CFCLOS
  *ENDIF
```

Fig. 5. Code for optimization of microactuator design (for the ANSYS system)

Software implementation of the algorithm, whose flow diagram is shown in Fig. 4, is presented in Fig.5. In the ANSYS system when changing the geometry of micro actuator, the working window has to be cleared with the operator / CLEAR, unlike boundary conditions. After this command all variables are cleared. This problem is solved by storing all the variables in the parametr.txt file. After using CLEAR operator all variables are read from this file again. That is why it is defined in the program that before starting to implement macros named ElectrActuator.txt (Fig. 2.), which has an operator / CLEAR, to save all variables in the file parametr.txt. One parameter, the length of micro actuator L2, is passed into macros ElectrActuator.txt. Other parameters remain unchanged. Example of the dependence of the bias voltage can be investigated by means of ANSYS without the use of additional methods [9]. After computing the macros writes into the file ElectrActuator.txt parametr.txt the bias for the ongoing L2.

Application of gold section search to automate the process of optimization of the design can be applied not only to micro actuators but to any other microdevices.

V. Results

Initially, the control program (Fig. 5) defines the maximum displacement for the minimum and maximum length of the comb. In Fig. 7 the decomposition for the initial deformation length of 300 µm micro actuator comb is shown. As it can be seen in the figure that the displacement for this length is 0.14 µm, while for the maximum value of l2=600 µm (Fig. 8) the displacement is 0.80 µm. Once offset for minimum and maximum length of the comb is defined the check is done whether the required displacement, in presented case DSPL = 0,20 µm, fits within the specified limits, if not, the program stops and the user needs to change the minimum or maximum values. If the desired value fits the prescribed limits then the selection of the optimal length of the micro actuator comb is continued.

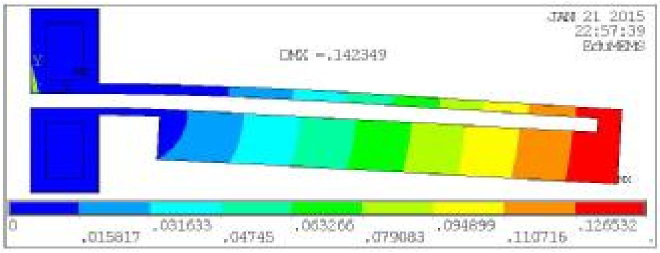

Fig. 7. Plate deformation for l2=300 µm.

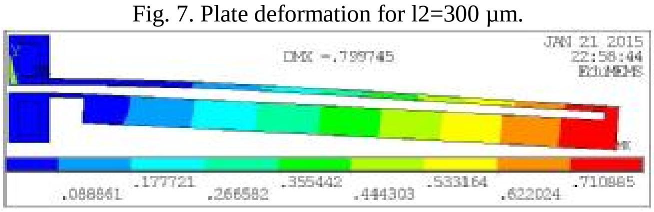

Fig. 8. Plate deformation for l2=600 µm.

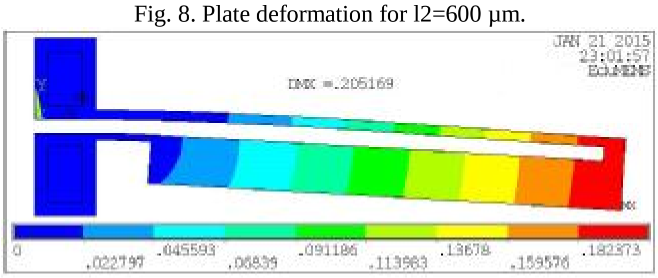

Fig. 9. Plate deformation for l2=600 µm.

As a result of applying the golden section search to optimize the design, we found with six iterations the required length of the micro actuator comb to provide the desired displacement of 0.20 µm. In this case, the required length of the comb is 343.76 µm (see. Fig. 10), and displacement was 0.205 µm (see Fig. 12), very close to the desired 0.20 µm. To increase accuracy, one has to change the program accuracy setting Accur from the current 0.01 to 0.005 for example (Fig. 5). The vari able Accur is used as a condition to stop calculation. If the difference between the latest and the previous resulting values of displacement is less than Accur, the calculation is terminated. If not then they calculation is repeated until it finally complies with this condition.

During the execution of every iteration the decomposition of deformations are stored as image files that are presented for example on Fig. 7 - Fig. 9. Additionally, one can store other intermediate results.

Upon completion of the required calculations the comb length and displacement obtained for a given length are written to a text file, an example is presented in Fig. 10.

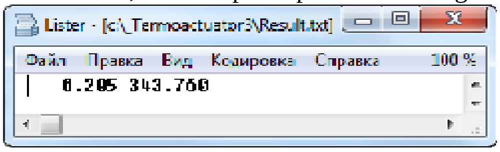

Fig. 10. File results of Golden Section Search Method

Similar calculation has been done using of bisection method. Results of all iterations of the Golden section search method and Bisection method are presented in Fig. 11. Results show that the Golden section search method got the given parameters during 6 iterations, but the bisection methods needed 8 iterations. In Fig. 11. From left to right are presented time spent for each iterations, length of the micro actuator comb, and resulted deviations. The figure shows that application of the Golden section search method to get the targeted deviations needed 2 minutes less the Bisection method.

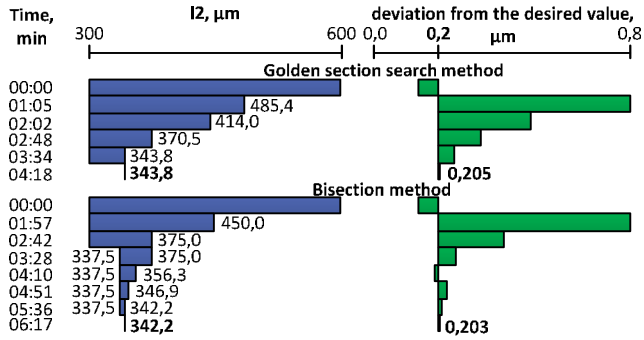

Fig. 11. Results for each iteration.

XI. Conclusion

It has been proposed for the first time to use golden section search to optimize the micro actuator design in the ANSYS system. This method has made possible automating the process of selecting the desired length of actuator comb for a chosen displacement taking into consideration the permissible error. For comparison, calculations were done for the bisection method. As we anticipated, the Golden section search method is more effective and we recommend applying it in the future. The program for the system ANSYS was developed, which allows both automating the process of search and building graphical dependencies.

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