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OPTIMIZATION OF MICROELECTRIC ACTUATOR DESIGN USING GOLDEN SECTION SEARCH TO GET THE DEFINED OUTPUT CHARACTERISTICS

ОПТИМІЗАЦІЯ КОНСТРУКЦІЇ МІКРОАКТУАТОРА З ВИКОРИСТАННЯ МЕТОДУ ЗОЛОТОГО ПЕРЕРІЗУ ДЛЯ ОТРИМАННЯ ЗАДАНИХ ВИХІДНИХ ХАРАКТЕРИСТИК

The article presents an example of the usage of golden section search to select the comb length of MEMS el electro-actuator to get the desired displacement at a given voltage heating. The proposed solutions are implemented as software code in the ANSYS system.

Key words: electro-actuator, computer-aided design, MEMS, finite element method, golden section search.

Подано приклад застосування методу золотого перерізу для добору довжини гребеня МЕМС-електроактюатора з метою отримання бажаного переміщення (displacement) при заданій напрузі нагріву. Запропоновані рішення реалізовані у вигляді програмного коду для системи ANSYS.

Ключові слова: електроактюатор, САПР, МЕМС, метод скінченних елементів, метод золотого перерізу.

Introduction

Recently thermo-electric micro actuators [1, 2], producing linear motion upon temperature change caused by Joule heating, have attracted a lot of attention [3-6]. These devices can have dimensions measured in micrometers and are produced mostly of polysilicon (theoretically can be made of any conductive material).

Electric actuators are mainly used to position micro-mirrors or move micro devices. To increase the effective force, multiple actuators can be combined together.

The main objective of the analysis is to calculate the actuator spike deflection that depends on the voltage applied to the contact areas.

When designing electric actuators, engineers are facing the task to create a structure that would ensure the necessary deflection for a given voltage. A lot of time is spent to optimize the design in order to obtain optimal output characteristics. There are many ways to optimize the design. One of these methods is the use of genetic algorithms, an example of which is presented in [7]. 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 used in ANSYS system. The obtained decisions show that to calculate the length of the micro actuator comb that would allow obtaining the desired bias voltage for a given heat, it is best to use the golden section search [8].We decided to develop both an algorithm that would allow to set the desired length of comb using the golden section search and the software to implement the proposed solution. That made it possible to automate the research process in the ANSYS system.

The principle of operation and design

Thermal-electrical actuator, which is used in MEMS, 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. Note that the resistance of a thin beam is larger than that of the plate. Thus, a 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 is presented in Fig. 1.

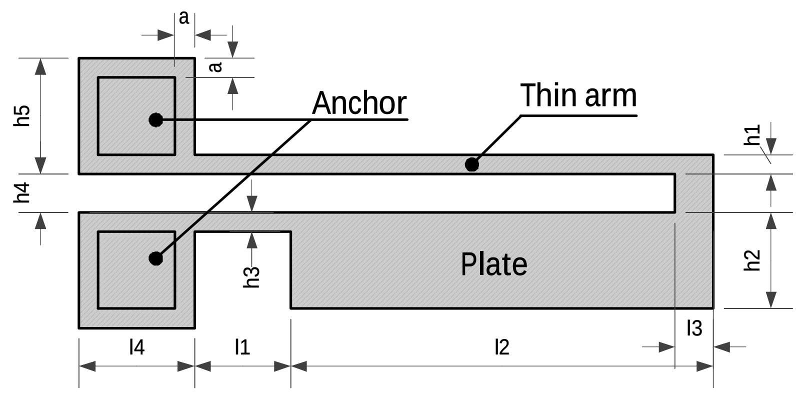

Fig. 1. Design of thermal-electrical actuator

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, which would allow determining the offset for the given design parameter constants. Examples of the code for the ANSYS system are presented in Fig. 2. The program defines all parameters, which are read from the parametr.txt file, except l2 which is the length of the micro actuator comb, as shown in Fig. 1. The program builds geometry, detects material properties [9], creates the finite element mesh and detects the specified boundary conditions and, finally, sets the MUSUM variable to the maximum displacement of the micro actuator comb. Any other variable(s) can be read 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.

Using the gold section search to optimize micro actuator

The algorithm of the golden section search [8] 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.):

$$x_{cep} = x_1 + 0.618\left(x_2 - x_1\right) \quad (1)$$

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

$$E = \left(0.618\right)^{1-n} \quad (2)$$

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:

$$\left|x_{n+1} - x_n\right| \le e \quad (3)$$

where e is a defined error.

```
/CLEAR,START
/CWD,'C:\_Termoactuator'
/units, uMKS
/RGB,INDEX,100,100,100,0
/RGB,INDEX,0,0,0,15
/NOPR
KEYW,PR_SET,1
KEYW,PR_STRUC,1
KEYW,PR_THERM,1
KEYW,PR_ELMAG,1
KEYW,MAGELC,1
KEYW,PR_MULTI,2
PARRES,NEW,'Parametr','txt',' '
h1=7
h2=35
h3=5
h4=10
h5=60
l1=40
l3=15
l4=45
s1=3
s2=2
a=10
/PREP7
TOFFST,273
tref,22
ET,1,SOLID227,111!Structural-thermoelectric
tetrahedron
!KEYOPT,1,1,111
mptemp,1, 25,125, 225, 325, 425, 525
mptemp,7, 625, 725, 825, 925,1025, 1125
mpdata,ALPX,1,1,2.556e-06, 3.195e-06,      3.590e-
06, 3.832e-06, 3.986e-06, 4.093e-06
mpdata,ALPX,1,7,4.179e-06,4.255e-06,4.324e-06,
4.387e-06,4.441e-06,4.494e-06
mpdata,KXX,1,1, 147.2e6, 99.9e6, 72.8e6, 57.7e6,
48.8e6, 42.8e6
mpdata,KXX,1,7, 38.1e6, 34.1e6, 30.8e6, 28.7e6,
27.5e6, 26.1e6
mp,EX,1, 170e3
mp, PRXY,1, 0.29
mp, RSVX,1, 4.20e-10       ! Resistivity
mp, DENS,1, 2330e-18       ! Density kg/µm3
k,1,0,0             ! Define keypoints
k,2,0,h5
k,3,l4,h5
k,4,l4,h1
k,5,l4+l1+l2,h1
k,6,l4+l1+l2,-(h4+h2)
k,7,l4+l1,-(h4+h2)
k,8,l4+l1,-(h4+h3)
k,9,l4,-(h4+h3)
k,10,l4,-(h4+h5)
k,11,0,-(h4+h5)
k,12,0,-h4
k,13,l4+l1+l2-l3,-h4
k,14,l4+l1+l2-l3,0
k,15,0+a,0+a             ! Define contact
k,16,0+a,h5-a
k,17,l4-a,h5-a
k,18,l4-a,0+a
k,19,l4-a,-h4-a
k,20,l4-a,-(h4+h5)+a
k,21,0+a,-(h4+h5)+a
k,22,0+a,-h4-a
a,1,2,3,4,5,6,7,8,9,10,11,12,13,14 ! Define area
vext,1,,,,,-s1   ! Extrude area by the out-of-plane size
a,15,16,17,18 ! Define area
vext,17,,,,,s2   ! Extrude area by the out-of-plane size
a,19,20,21,22 ! Define area
vext,23,,,,,s2   ! Extrude area by the out-of-plane size
VGLUE,All
SMRT,5
VMESH, All

/GO
DA,18,ALL,0
DA,24,ALL,0
DA,24,VOLT,0
DA,18,VOLT,5
DA,18,TEMP,22
DA,24,TEMP,22
KEYOPT,1,1,111
KEYOPT,1,2,0
KEYOPT,1,4,0
KEYOPT,1,9,0
KEYOPT,1,10,0
FINISH
/SOLU
SOLVE
FINISH
/POST1
SET,FIRST
/EFACET,1
/SHOW,JPEG,,0
PLNSOL, U,SUM, tvg,1.0
*GET,MUSUM,PLNSOL,0,max
/SHOW,CLOSE
FINISH
```

Fig. 2. Program code for ANSYS

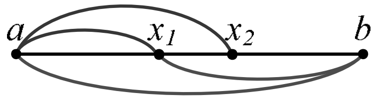

Fig. 3. Example of point selection in the golden section search [8]

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.

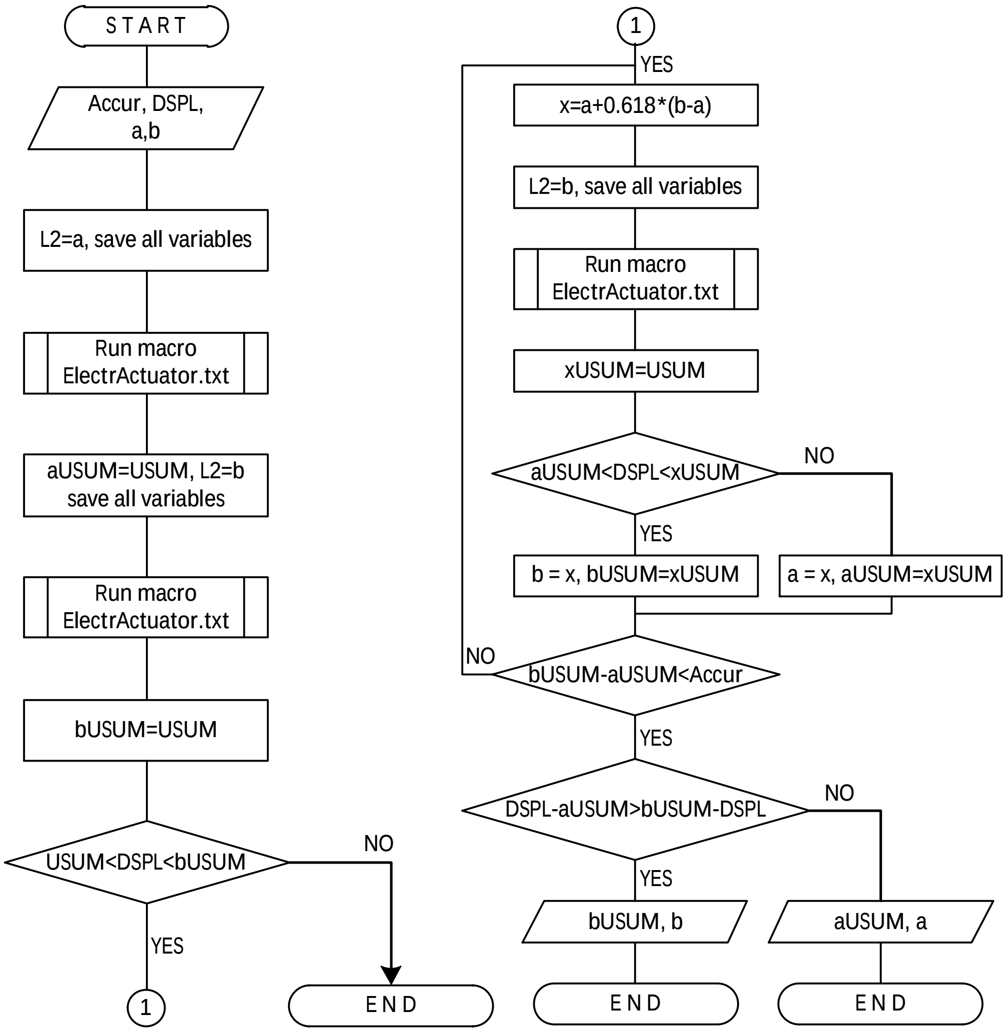

Fig. 4. The flow diagram of algorithm for automated selection of actuator parameters

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.

```
/CLEAR,START
/units, uMKS
Accur=0.05        ! Accuracy um
DSPL=0.15         ! Displacement Desired value movement
a1=200            ! Initial value l2
b1=400            ! Final value l2
l2=a1
PARSAV,SCALAR,'Parametr','txt',' '
/INPUT,'ElectrActuator','txt','C:\_Termoactuator1\',, 0
aUSUM=MUSUM
l2=b1
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
        x1=a1+0.618*(b1-a1)
        l2=x1
        PARSAV,SCALAR,'Parametr','txt',' '
        /INPUT,'ElectrActuator','txt','C:\_Termoactuator1\',, 0
        xUSUM=MUSUM
 *ENDIF
  *IF,DSPL,GT,aUSUM,AND,DSPL,LT,xUSUM,THEN        b1=x1
          bUSUM=xUSUM
  *ELSE
          a1=x1
          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,b1
(2F8.3)
                *CFCLOS
        *ELSE
                *CFOPEN,Result,txt,C:\_Termoactuator1\,
                *VWRITE,aUSUM,a1
(2F8.3)
                *CFCLOS
   *ENDIF
```

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

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.

Automation of graphical dependencies

To get the data needed to build the graphical dependencies one needs each time to change the applied voltage or other parameters. The program was developed that allows building automatically a graphical dependency [10]. Once geometry has been built and material properties set up [11], partitioning on the finite element mesh done and boundary conditions set up, to automate recording of the obtained results the developed program for ANSYS system, presented in Fig. 6, is used.

```
PV=1    ! Starting voltage
KV=5    ! End voltage
SV=1    ! Step
*SET,NN,((KV-PV)/SV+1)
DIM,VV,ARRAY,NN      ! Revelation array  VV
NPP=1
VPLOT
/SOL
*DO,V,PV,KV,SV
/GO
DA,24,VOLT,V ! Boundary conditions
*SET, VV(NPP),V
NPP=NPP+1
/STATUS,SOLU
SOLVE
*ENDDO
FINISH            !
*DIM,MVOLT,ARRAY,NN       ! Revelation
array MVOLT
*DIM,MUSUM,ARRAY,NN       ! Revelation
array MUSUM
*DIM,MTEMP,ARRAY,NN       ! Revelation
array MTEMP
/POST1
SET,FIRST                 !Read the first results
/EFACET,1
/SHOW,JPEG,,0             !Makes a screenshot
PLNSOL, VOLT,, , tvg,1.0
*GET,MVOLT(1),PLNSOL,0,max
PLNSOL, U,SUM, tvg,1.0
*GET,MUSUM(1),PLNSOL,0,max
PLNSOL, TEMP,, tvg,1.0
*GET,MTEMP(1),PLNSOL,0,max
*DO,NT,2,NN,1
SET,NEXT                  !Read the NT results
PLNSOL, VOLT,, , tvg,1.0
```

```
/SHOW,JPEG,,0
/SHOW,TIFF,,0
/AXLAB,Y, Maximum temperature [C]
/AXLAB,X, Voltage [V]
XVAR,4
PLVAR,2,
/SHOW,CLOSE
FINISH  VPUT,MUSUM(1,1,1),200   ! ID:  3
REALVAR,3,200,,,MUSUM
VPUT,MVOLT(1,1,1),200   ! ID:  4
REALVAR,4,200,,,MVOLT
! Maximum displacement of the applied voltage
/AXLAB,Y, Maximum displacement [m]
/AXLAB,X, Voltage [V]
/SHOW,JPEG,,0
/SHOW,TIFF,,0
JPEG,TMOD,1
XVAR,4
PLVAR,3,
/SHOW,CLOSE
FINISH
/POST26
FILE,'file','rst','.'
/UI,COLL,1
NUMVAR,200
SOLU,191,NCMIT
STORE,MERGE
FILLDATA,191,,,,1,1
REALVAR,191,191
VPUT,MTEMP(1,1,1),200   ! ID:  2
REALVAR,2,200,,,MTEMP
PLNSOL, U,SUM, tvg,1.0
*GET,MUSUM(NT),PLNSOL,0,max
PLNSOL, TEMP,, tvg,1.0
*GET,MTEMP(NT),PLNSOL,0,max
*ENDDO
*GET,MVOLT(NT),PLNSOL,0,max
```

Fig. 6. Code of program that automates system graphic dependencies for ANSYS

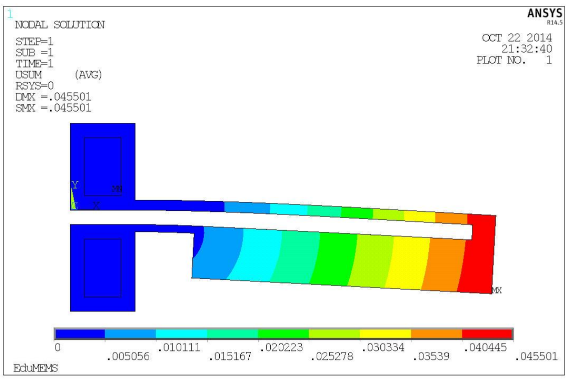

Fig. 7. Deformation decomposition for l2=200 mcm

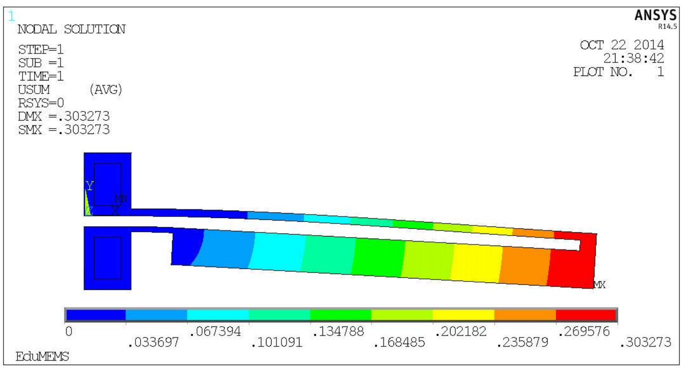

Fig. 8. Deformation decomposition for l2=400 mcm

The result of the program (Fig. 6) will be the distribution of stresses and deformations in the plate accelerometer for different voltages. The program is based on data previously recorded into files and automatically builds graphical dependencies.

The obtained 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 200 µm micro actuator comb is shown. As it can be seen in the figure that the maximum displacement for this length is 0.045 µm, while for the maximum value of l2=400 µm (Fig. 8) the maximum displacement is 0.30 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 = 15 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.

As a result of applying the golden section search to optimize the design, we found with three iterations the required length of the micro actuator comb to provide the desired displacement of 0.15 µm. In this case, the required length of the comb is 305.564 µm (see. Fig. 9), and displacement was 0.14966 mm (see Fig. 12), very close to the desired 0.15 µm. As we can see the error is of the order of 10^{-3} µm. To increase accuracy, one has to change the program accuracy setting Accur from the current 0.05 to 0.005 for example (Fig. 5). The variable 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 each iteration the decomposition of deformations are stored as image files that are presented for example on Fig. 7 – Fig. 8 and Fig. 10. 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. 9.

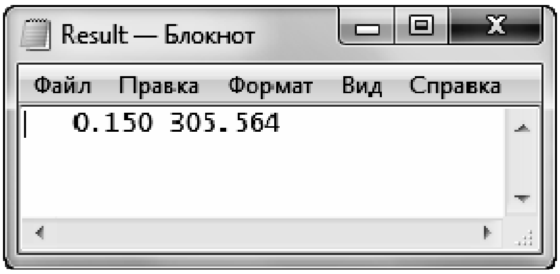

Fig. 9. File of results

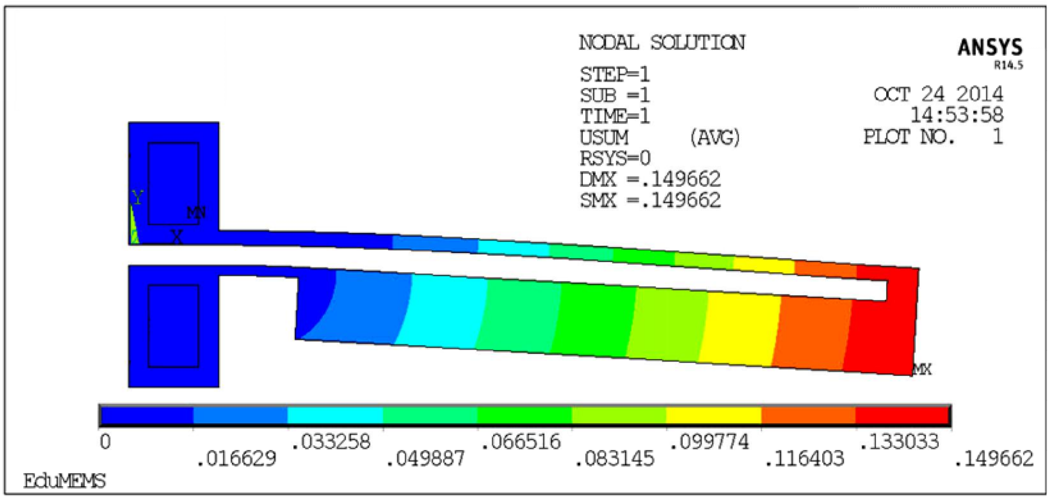

Fig. 10. The maximum displacement

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.

To automate the research process, the program for the system ANSYS was developed, which allows both automating the process of search and building graphical dependencies.

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