Application of a Genetic Algorithm for Dimension Optimization of the MEMS-based Accelerometer

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Abstract—**A system for optimizing the size of MEMS-based accelerometer has been developed to meet the standards for the sensitivity and survivability, etc. A code has been written for the system ANSYS, allowing automatically conducting modal analysis or other research of MEMS design based on dimensions obtained from other system.**

Index Terms—**MEMS; accelerometer; genetic algorithm; computer-aided design.**

I. Introduction

Today, many scientific papers are devoted to the automated design of MEMS devices [1]-[3]. One of the next stages of design automation is the use of optimization to find the optimal design parameters of the accelerometer. That is the reason we devoted this research to the use of genetic algorithms for finding the optimal design parameters of accelerometer.

II. Construction and Principles of Work of MEMS-based Acelerometer

MEMS accelerometer is used in many domains, namely, car airbag systems, computer consoles, mobile phones, pagers, laptops, digital cameras, robotics, etc. In each of the cases, the size and accuracy are the most critical characteristics of the sensor, so that a size of crystal that hosts micro device was selected as optimization criteria.

The sensitivity of these sensors is proportional to the length of the mass. These sensors return electrical signal proportional to the specified offset. Using Hooke's law and Newton's second law, the acceleration of the mass can be easily identified: $kx = ma$.

The design of the MEMS-based accelerometer is shown in Fig.1 [10,12]. Ideally elastic elements of the accelerometer have to be as long as possible, and their mass as large as possible. Therefore, there is the problem of finding such design parameters of the accelerometer, in which the small size of the accelerometer would provide the best performance, namely: maximum displacement of the seismic mass with minimal acceleration, which will lead to high sensitivity.

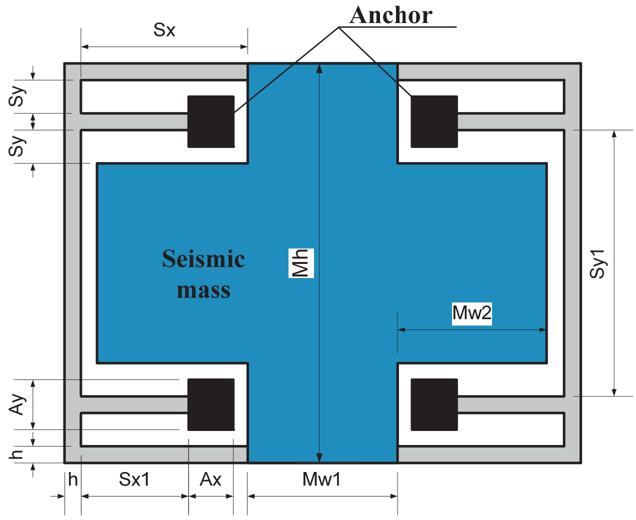

Figure 1. The design of microelectromechanical accelerometer.

During the analysis of the properties of elastic elements for a given set of design parameters, the concept of the superposition sum of forces and moments at each crossing of beams is used. These results include forces and moments in places of maximum pressure and the total effective bending constant for the entire system. These equations are later used in optimizing the size of the construction of accelerometer.

III. Choice of Optimization Method

Optimization methods were analyzed for their suitability in optimizing the design of a typical accelerometer. After the analysis, the method based on genetic algorithms was selected. Genetic algorithms are a powerful tool for solving a variety of combinatorial and optimization problems (4). Therefore, genetic algorithm is included into the standard toolkit of predictive calculations.

Genetic algorithm follows a simple iterative process to minimize the objective function that is given:

$$S = \{Sx,\ Sx_1, Sy,\ Mw_1\}. \qquad (1)$$

Simple genetic algorithm randomly generates initial structure of population. The genetic algorithm is an iterative process that continues till the specified number of generations is executed or any other criterion of stop is met. Each generation of the genetic algorithm is realized in proportion to fitness selection, single-point crossover and mutation. Firstly, proportional selection assigns each structure the probability Ps(i), which represents the ratio of its fitness to the total fitness of the population:

$$P_S(i) = \frac{f(i)}{\sum_{i=1}^{n} f(i)} . \quad (2)$$

Then there is a selection (with replacement) of all n individuals for further genetic processing, according to the value $P_S(i)$ .With this selection, members of the population with higher fitness are likely to be chosen more often than individuals with low fitness. After the selection, n elected individuals are randomly divided into $n/2$ pairs. For each pair with probability P_S a crossover can be applied. In accordance with the probability of $1-P_S$ crossover does not occur and the unchanged individuals move to the stage of mutation. If crossover is done by replacing the parents with their descendants and then pass to mutations.

The flowchart of the genetic algorithm is shown in Fig. 2.

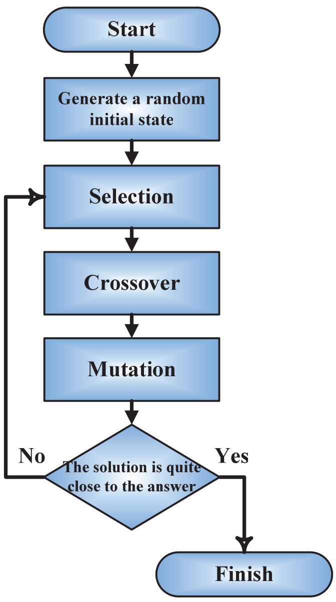

Figure 2. Flow of the genetic algorithm.

In conclusion it can be stated that genetic algorithms are an effective procedure to find the optimal solution, but their effectiveness largely depends on such parameters as the method of generating solutions, selection criteria of the best offspring, crossover methods etc.

IV. Restrictions

Constraint parameters are defined by manufacturing process, financial constraints, material properties and design goals. In our case, they are given by the following equations:

Restrictions of equality:

$$h = 3\,\mu m,\ \ b = 3\,\mu m,\ \ Mw1 = 200\,\mu m \quad (3)$$

Restrictions of inequality:

$$\begin{aligned} &Sx \geq Sx_1 \\ &Sx_1 \geq 35\,\mu м \\ &Sy \geq 50\,\mu м \\ &Sx \geq Sx_1 + Ax \end{aligned} \quad (4)$$

Because of these limitations, we are trying to achieve certain engineering goals. These goals represent the input task of design and are as follows:

The minimum sensitivity of the accelerometer: $sens_{min} \leq$ *0,0003g;* maximum survivability of the accelerometer: $sur_{max} \geq$ *1000g;* the maximum area of the crystal: $S_{accel} = Mh(2 \cdot Sx + 2 \cdot h + Mw_1) \leq 200,0\,\mu m^2$.

To find the optimal size of the construction of the accelerometer the developed system presented in Fig. 3 was used. By providing optimization options, the number of iterations and the number of populations the program is able to calculate the optimal size of the accelerometer, which meet the set of limitations and the objective function and present the results of calculations in the window. Based on the main dimensions, all other sizes of accelerometer construction are calculated.

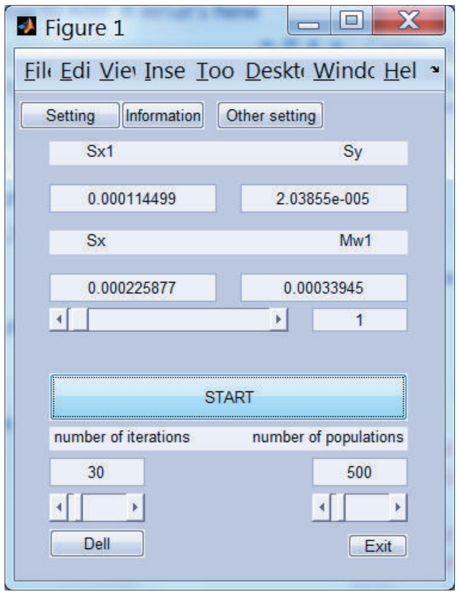

Figure 3. UI of the developed system.

V. Verification of the Results of Optimization

The next step after optimization using genetic algorithms is the verification of the obtained results and further research. In order to do this, we designed the accelerometer in ANSYS based on the dimensions obtained from the developed optimization system. Our Ansys script is shown in Fig. 4. The next step is to run the script in the ANSYS . The resulting geometry of the optimal-size accelerometer is shown in Fig. 5.

```
/PREP7
Sy = 7.024e-005      Sx = 3.249e-004      Sx1 = 2.132e-004
Mw1 = 2.00e-004      h=5e-6     b=3e-6    Sy1=400e-6
Mh=Sy1+4*Sy+4*h  y=Mw1/2+Sx+h  !      Ax=y-Sx1-h-Sy/2
Ay=Sy+h
RECTNG,0,Mh/2,0,y,
RECTNG,Mh/2-h,Mh/2-h-Sy,Mw1/2,y-h,   !
RECTNG,Mh/2-2*h-Sy,Mh/2-2*h-2*Sy,Mw1/2,y-h,   !
RECTNG,Mh/2-h-Sy,Mh/2-2*h-Sy,Mw1/2,y-Sx1-h,   !
RECTNG,0,Mh/2-2*h-2*Sy,y-h,y-h-Sy/2,   !
FLST,3,4,5,ORDE,2
FITEM,3,2
FITEM,3,-5
ASBA,       1,P51X
RECTNG,Mh/2-h-Sy/2,Mh/2-h-Sy/2-Ay,Mw1/2+Sy/2,y-Sx1-h,   !Анкер
FLST,3,2,5,ORDE,2
FITEM,3,1
FITEM,3,6
ARSYM,X,P51X, , , ,0,0
FLST,3,4,5,ORDE,3
FITEM,3,1
FITEM,3,-3
FITEM,3,6
ARSYM1,Y,P51X, , , ,0,0
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Figure 4. Example of the developed code for ANSYS.

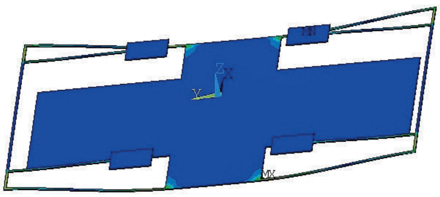

Figure 5. Automatically generated design of the accelerometer.

The next step is to check whether all constraints are satisfied, or it is necessary to conduct a modal analysis in the ANSYS system.

VI. Conclusions

A system for optimizing the design of a typical MEMS accelerometer that meets a set of specified constraints was developed. Because of the complex nature of the problem, an optimization algorithm based on genetic algorithms was implemented.

Aknowledgements

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