Features of the Optimization of Mechanical Component Macromodels

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Abstract – **The features of the optimization of reduced circuit macromodels of mechanical components by means of the circuit design software's parametrical optimization blocks are considered in the paper. A list of the tasks to be settled at the stage of the object parameter optimization is assigned. The main problems appeared by solving each of the tasks are indicated.**

Keywords – **Simulation, Optimization, MEMS.**

I. Introduction

The considered in [1] technique to construct macromodels of the MEMS mechanical components as equivalent reduced RLC-circuits for the joint simulation of compound electromechanical devices includes the stage of the optimization of an obtained macromodel by means of the proper circuit design software's parametrical optimization blocks. However, the process of macromodel parameters adjustment is difficult in case of the optimization of macromodels with a few elements and relatively low accuracy. This paper deals with a number of the features of the optimization of such macromodels.

II. Optimization Stage Tasks

As an example to demonstrate the features of the optimization of mechanical component macromodels the task to adjust self-resonant frequencies of a mechanical object is considered. An adjustment of one work frequency value for the obtained macromodels does not present difficulties usually. The main problems appear when it is required to get correct values for the set of the frequencies in a specified range. By this, a number of tasks arise, which have to be resolved:

- to define a number of variable parameters;
- to define a set of variable parameters;
- to define parameter variation ranges;
- to define parameters to calculate output characteristics;
- to choose the objective function (OF) type and the optimization method.

Defining a number of variable parameters

Increasing number of variable parameters leads to OF calculation complication as well as increases probability of optimization procedure failure. However, a little number of parameters does not allow adjusting some frequencies at once. It is experimentally determined that an optimal number of variable parameters NVar $\in$ [Nf, 2Nf] where Nf is a number of frequencies to be adjusted.

Defining a set of variable parameters

To select elements to be included into a set of variable parameters, it is needed to take into account the features of circuit equivalents of mechanical components with some degrees of freedom.

In the presented on Fig. 1 equivalent circuit of a beam with three degrees of freedom (Fig. 2) «Ox» and «Oy,Oz» subcircuits are independent and connected only by zero (basis) node. «Ox» subcircuit simulates a beam tension while «Oy,Oz» subcircuit simulates a beam bending. During the reduction process with using the described technique [2] this feature (presence of some subcircuits) remains permanent. So, the obtained reduced macromodel (Fig. 3) has such feature also, in case of presence of non-reduced nodes or nodes with a time constant greater than the threshold value τ_{min} provided by user in the respective subcircuit (otherwise, such subcircuit may be fully cut down).

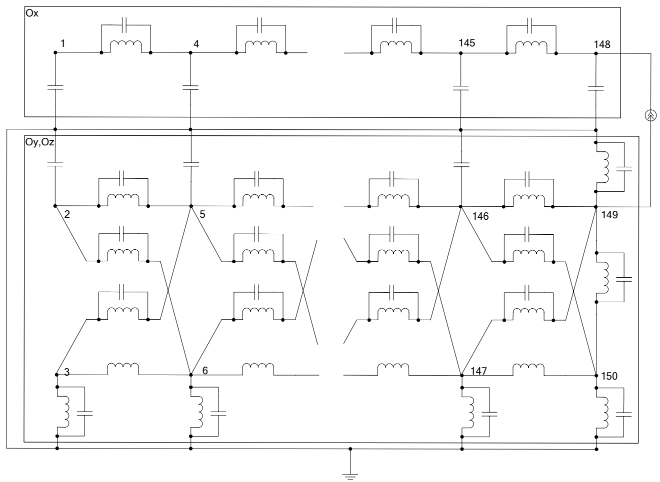

Fig. 1 Beam with three degrees of freedom equivalent circuit

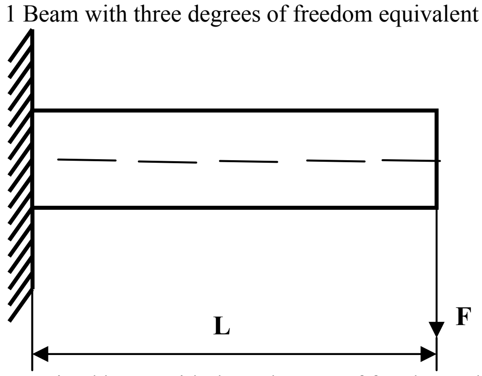

Fig. 2 Fixed beam with three degrees of freedom scheme

It is obviously that if there are no elements of one of the subcircuits in the variable parameter set, then the optimization of the frequencies generated by this subcircuit is impossible. In addition, if the accuracy of a subcircuit with no elements in the variable set is less than the required by the optimization task for whole macromodel one, then there will be no result.

Moreover, the presence of the independent subcircuits in the reduced macromodel allows applying optimization methods to adjust frequencies in each subcircuit successively

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decreasing a number of simultaneously used variable parameters and simplifying OF calculation. For the example in question, the fourth frequency's optimal value is reached firstly by variation of values of some «Ox» subcircuit elements (this is only frequency of first four ones related to the beam tension), and then those elements' obtained values are used to adjust first three frequencies related to the beam bending by variation of values of certain «Oy,Oz» subcircuit elements [3].

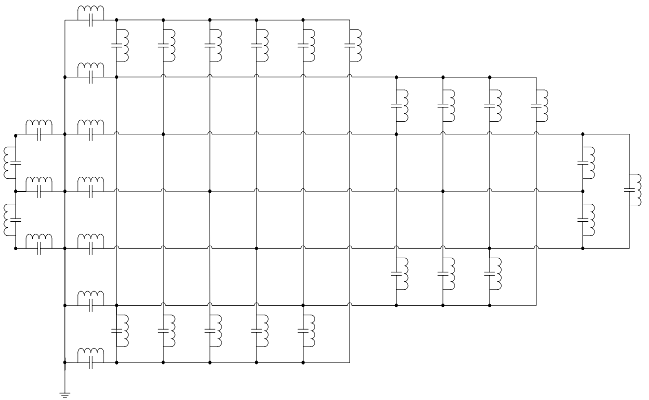

Fig. 3 Beam reduced circuit macromodel

Defining parameter variation ranges

The problems related to defining a number of variable parameters and their variation ranges could be revealed by the following example. On Fig. 4 a macromodel of the beam with one degree of freedom is presented.

```
Circuit Beam;                C2(100,0) = 6.3;
J1(100,0)=-100;              C3(23,50) = -0.11667;
C1(82,100) = -0.11667;       C4(23,0) = 17.3833;
L10(100,0) = -34161.8;       C5(50,82) = -0.11667;
L11(23,50) = 1.35e-10;       C6(0,50) = 20.65;
L12(23,0) = 1.15e-10;        C7(0,82) = 17.5;
L13(50,0) = -16435.9;        L8(82,100) = 9e-11;
L14(50,82) = 1.6e-10;        L9(82,0) = -580750;
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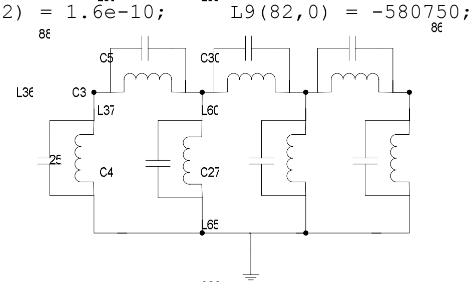

Fig. 4 Beam with one degree of freedom reduced macromodel

The optimization task was to adjust circuit parameters to get values of two first self-resonant frequencies equal to 1336.3 and 4009.3 Hz correspondingly with an accuracy of 0.1%. The inclusion of too wide parameter variation range could lead to the effect shown on Fig. 5. In this case there are three self-resonant frequencies in the 15 – 4500 Hz range. By this, first and third self-resonant frequencies correspond to the desired ones with the required accuracy. An example of the simulation results under the reasonably provided variable parameters is given on Fig. 6.

```
VARPAR L8(1e-12,1e-9);     VARPAR L11(1e-12,1e-9);
VARPAR L9(-6E5,-56E4);     VARPAR L12(1e-12,1e-9);
VARPAR L10(-6E4,-2E4);     VARPAR L14(1e-12,1e-9);
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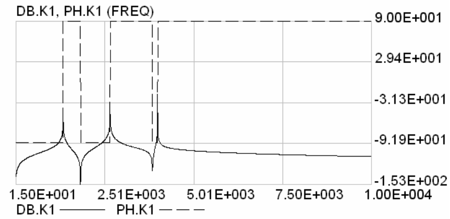

Fig. 5 Frequency analysis results under the false selection of the parameter variation ranges

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VARPAR L8(8e-11,1e-10);   VARPAR L12(1e-10,2e-10);
VARPAR L11(1e-10,2e-10);  VARPAR L14(1e-10,2e-10);
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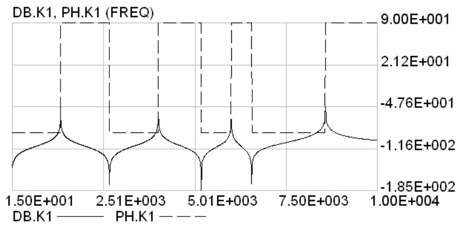

Fig. 6 Frequency analysis results under the proper variable parameters

Defining parameters to calculate output characteristics

When adjusting self-resonant frequencies, the capabilities of the NetALLTED software's task control language has been used for the optimization process [4], namely the FIX directive:

FIX A1 = MAXA (*arg*, *Tb*, *Te*).

MAXA directive allows defining time or frequency when the argument *arg* reaches its maximum value in the specified time or frequency range *Tb – Te*. If this range is chosen to be too narrow, there is a probability to find a local maximum that does not match a self-resonant frequency (Fig. 7). If the range is chosen to be too wide, additional self-resonant frequencies *f** which does not correspond to the real object's self-resonant frequencies *fp* may appear there (Fig. 8).

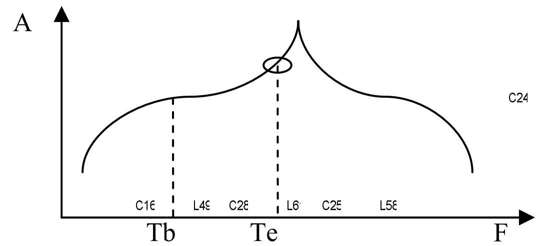

Fig. 7 Defining a function maximum when too narrow frequency range is selected

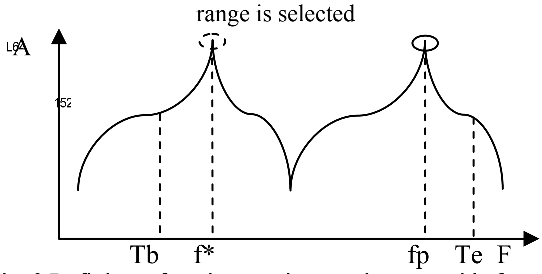

Fig. 8 Defining a function maximum when too wide frequency range is selected

Choosing the OF type and the optimization method

The OF type is to be chose taking into account the requirements of a designer which sets the task for optimization. However, when adjusting frequencies which are long distance apart (f_n>=10*f_1), it is recommended to make use of OFs estimating a relative error of the calculations.

In general case, when choosing the optimization method, it is recommended to avoid those ones which use estimating of derivatives due to a large spread of the obtained macromodels' element values. Usage of the random search methods increases a number of OF estimations significantly, however OF single estimation costs are usually small owing to not great circuit sizes and absence of non-linear components. Also this leads to the elimination of the problem with a good initial estimate choice.

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III. Conclusion

The tasks considered are only a small part of the problems arising when adjusting parameters of circuit macromodels by means of the circuit design software's parametrical optimization blocks. It is obviously that it is needed to take into account the features of the macromodels being obtained as well as capabilities and features of the parametrical optimization block of a specific software when choosing a set of the variable parameters and their variation ranges.

Taking into account a presence of separate subcircuits in the source macromodel is critical for the entire optimization process since a variable parameter set depends on this circumstances, while skipping such a feature may lead to the optimization task statement which will have no solution. Moreover, successive optimization of separate subcircuits more likely considerably simplifies obtaining object's compact macromodel with a given accuracy.