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EVALUATION THE SOLUTION TIME OF FINITE ELEMENT ANALYSIS USING GAUSSIAN ELIMINATION

The paper describes method allowing predicting solution time of finite element analysis. The method is based on statistical data and computational complexity of software algorithms.

Key words: FEM, CAE, computational complexity, solution time.

Описано метод, що дає змогу прогнозувати час виконання скінченно-елементного аналізу. Метод оснований на статистичних даних і складності обчислення програмно-реалізованих алгоритмів.

Ключові слова: скінченно-елементний аналіз, CAE, складність обчислення, час рішення.

1. Demand for solution time prediction

Nowadays FEM is the most widely used method for the analysis of physical problems described by differential equations. Its main advantages are the high flexibility and versatility, which makes its use for solving a variety of physical problems. On the other hand, the method takes a lot computing resources. And the more accurate results are needed, the more resources are required. Engineers always need to balance between accuracy and reasonable solution time.

The article describes methods that allow one to predict how much time will be spent on the solution by FEM. With these data engineer can decide whether to continue the solution of the problem, or to return to the configuration of analysis so the solution be obtained within a reasonable time.

2. The principle of solution time prediction

The presented method for FEM solution time prediction is based on two components: known computational complexity of the solution algorithm; and collection of statistical data of solved of tasks.

Computational complexity is presented in the form of O-notation. Substituting specific values in its expression we obtain a number that we call coefficient of complexity. Solution time of task is almost proportional to complexity coefficient. This coefficient allows us to compare the complexity of different tasks. By this coefficient is searched the most close task from the statistics database. This task called basic sample. Now having time of solving the basic sample, we can make a start of predicting the solution timing of current task.

3. Determining computational complexity of the algorithm

The computational complexity function in some cases can be determined accurately, but in our case is not necessary. We use complexity function for comparison of tasks complexities. Mathematical notation, which allows to reject details of the algorithm analysis, is called asymptotic notation and is denoted by $O(f(N))$. When increasing the size of the input data, the contribution of constant factors and terms of lower order, which appear in the expression, is quite small for the exact solution time. Therefore we don't take it into account.

In the paper we predict the solution time of FEM in which for solving of algebraic equations using a Gaussian Elimination. As shown below, the main part of FEM solution time actually falls on the solution of equations. Detailed description of evaluation of computational complexity for study programs presented in [1].

Full expression of the computational complexity of the study program represented in eq. 1, where E – the number of elements in the finite element mesh, N – number of nodes in the mesh, W – width of banded matrix. The whole expression reduced to the member $O(NW)^2$, which represents the complexity of solving algebraic equations by the direct Gaussian Elimination method. Actually this expression we will use for determining the complexity coefficient.

$$O(E)+O(NW)+O(NW^2)+O(NW) = O(NW^2) \quad (1)$$

4. Database of solutions time statistics

The subsystem saves statistics of conducted analyses. This data is the basis for the prediction of solution time of following problems. The database stores the values for the so-called basic examples, the complexity of which is different, and is distributed according to a certain law. Database of statistics saves a pairs of two numbers for each basic example. The first number – a complexity coefficient derived from the function complexity NW^2, in which substituted the specific values of the arguments obtained from the properties of the constructed finite element mesh. The second number – a time spent for solving the problem (in milliseconds).

Table 1

Predicted solution time

№	*N*	*W*	*t exp, sec*	*t pre, sec*	δ, %
1	251001	502	536.42	546.93	1.92
2	75 651	502	165.20	164.84	0.22
3	38 160	361	43.00	basis	
4	27 391	302	14.35	21.60	50.52
5	7 360	161	1.12	1.65	47.32

Table 2

Predicted solution time

№	*N*	*W*	*t exp, sec*	*t pre, sec*	δ, %
1	251001	502	536.42	363.34	32.27
2	75 651	502	165.20	109.51	33.71
3	38 160	361	43.00	28.56	33.58
4	27 391	302	14.35	Basis	
5	7 360	161	1.12	1.10	1.79

As mentioned earlier, O-notation does not include terms of the lower orders, since their impact at big input data becomes insignificant. Therefore for small tasks solution time evaluation is less accurate, because the rejected terms have greater influence, and for large tasks the accuracy of evaluation significantly grows as the impact of the rejected terms are inappreciable here. Proof of this is the data from Table 1, where N – number of nodes in the finite elements mesh, W – width of the banded matrix, t_{exp} – solution time obtained experimentally, t_{pre} – predicted solution time. Here for predicting taken one example with known solution time labeled as *basis*. It is a basis for evaluation of solution time of other samples. Time solution is proportional to the coefficient of complexity. The solution time predicted by the following equation (2). Where *c* – marks parameters of current task, *b* – basic sample, *C* – complexity factor. For a more precise prediction of time solutions of small problems basic sample should be taken from the nearest coefficient of complexity. Forecasting error for small tasks caused by the rejected terms from the expression of complexity (1), which for small inputs have a greater impact. The Table 2 shows that when used small basis the prediction accuracy for small tasks significantly increased, but less decreased for large tasks.

$$t_c = \frac{N_c W_c^2}{N_b W_b^2} \cdot t_b = \frac{C_c}{C_b} \cdot t_b \qquad (2)$$

Distribution of basic examples in the database is due for small tasks should be taken closer in complexity basic samples. For small tasks the intervals between bases smaller, for larger intervals increase. For such a distribution is chosen exponential function (3).

$$C_i = C_{min} \cdot a^i;\ i \in 1,n \qquad (3)$$

$$a = (C_{max} - C_{min})^{1/n} \qquad (4)$$

where n – number of basic examples in the database, C_i – complexity of *i*-th sample, C_{min}, C_{max} – minimum and maximum complexities for basic samples. Substituting to function (3) the number of intervals *n* and boundary dimensions of problems C_{min}, C_{max} yields splitting of intervals with exponential increasing their lengths. This splitting allows you to store more basic examples for small tasks and less for larger ones. After each analysis the database is updated with new data of solution time. But now time is determined for the basic sample from known experimental data. Using the same equation (2), but now *c* denotes the arguments of the basic sample, *b* – current determined task.

5. Integration to FEM system

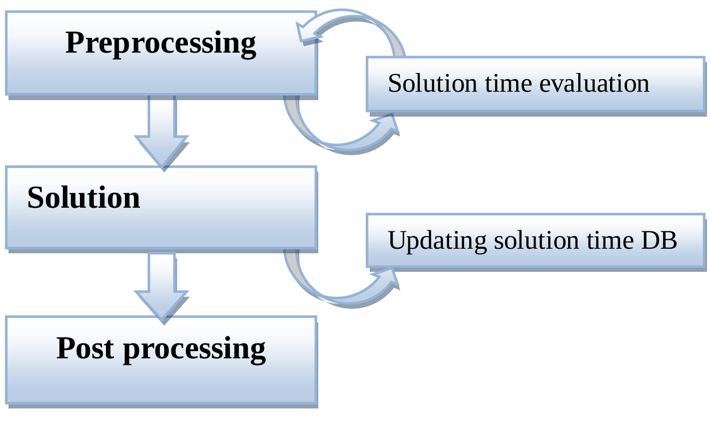

Fig. 1 Solution time evaluating subsystem in FEM software

Analysis of the finite element method consists of three main phases: preprocessing, solution and post processing (fig. 1). Preprocessing includes preparing input data for solving the problem: creating geometry models, setting boundary conditions, finite element mesh generation. The next phase solutions forms of system of linear algebraic equations and solve it. It is performed without the intervention of an engineer and takes the bulk of the computing time. Duration of this phase is forecasting by the subsystem. The last phase post processing includes processing and displaying of results.

Prediction of the solution phase requires known mesh parameters *N* and *W*. Some algorithms generating mesh determines this parameter even before the mesh is generated, others need to make a complete building of mesh. Having estimated solutions timing engineer can continue to implementation phase of the decision or, if the timing is not satisfied, return to the mesh settings. Upon completion of Solutions Phase new data about solving the problem updates database of statistics, which make the following prediction more accurate.

6. Conclusion

The present method of evaluation of FEM solution time can be easily integrated into CAE system. It requires no additional computational costs small sized statistics DB storage.

Solutions time forecasting subsystem allows engineers to accurately estimate the time required for FEM analyses. If timing does not satisfy, he can return to the correction of the model before start calculation.

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THE REGULARITIES OF MULTIBEAM ACOUSTIC WAVES INTERFERENCE IN MEMS CAVITY-TYPE STRUCTURES WITHOUT SHEAR STRESS. ANALYSIS BY THE ENVELOPE METHOD

In this paper the amplitude-phase spectra envelope method of multi-beam acoustic waves Fabry-Perot interference in MEMS cavity-type structures without shear stress at normal and oblique beam passing limits divisions is developed. It is found that the spectra analysis by the envelope method significantly broadens the application of an appropriate approach for nondestructive testing of thin film structure parameters. In addition, on the basis of the envelope function regularities the angular conditions of Pseudo effect manifestation for the binary interface in the spectra are grounded.

Key words: MEMS-structures, Fabry-Perot interference, amplitude-phase spectra.

Розроблено метод обвідних амплітудно-фазових спектрів багатопроменевої інтерференції Фабрі-Перо акустичних хвиль для МЕМС-структур резонаторного типу без зсувних напруг при нормальному і похилому проходженні променем меж поділів. Встановлено, що аналіз спектрів методом обвідних істотно розширює межі застосування відповідного підходу для організації неруйнівного контролю параметрів плівкових структур. Крім цього, на основі закономірностей обвідних обґрунтовано кутові умови прояву в спектрах псевдобрюстерівського ефекту для бінарної межі поділу.

Ключові слова: МЕМС-структури, інтерференція Фабрі-Перо, амплітудно-фазові спектри.

Introduction

The Fabry-Perot interferometry principle was discovered in [1] and is considered to be well studied in the acoustic and optical wave ranges [2, 3]. Nowadays this approach has formed the basis for a whole class of technical solutions such as the reconstruction of parameters of heterogeneous media [4–11], sensor