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(54) **METHOD FOR SIMULATING A PHYSICAL PROPERTY OF A TECHNICAL STRUCTURE BY A COMPONENT MODEL**

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G06G 7/56   (2006.01)
G06G 7/48   (2006.01)

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USPC **703/7**; 703/1; 703/5; 703/8

(58) **Field of Classification Search**
USPC 703/1, 5, 7, 8
See application file for complete search history.

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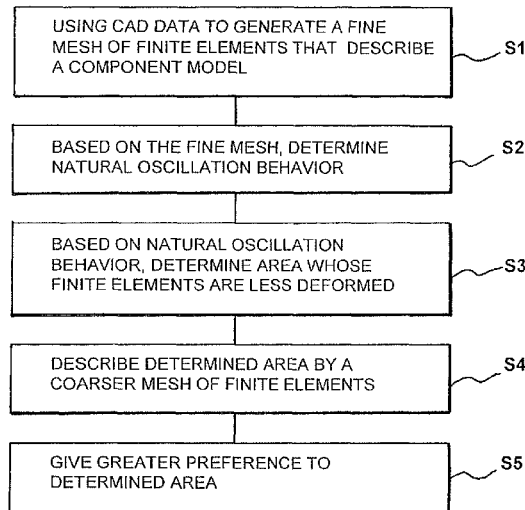*Primary Examiner* — Omar Fernandez Rivas
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(57)   **ABSTRACT**

In a method for simulating a physical property of a component model in the form of a computer accessible construction model of a technical structure, a mesh of a component model is automatically generated. The component model is first described by a fine mesh of finite elements, and, based on the fine mesh, the natural oscillation behavior of the component model is determined. Based on the natural oscillation behavior, at least one area of the component model is determined, whose finite elements are less deformed than those of another area of the component model. The determined area of the component model is then described by a coarser mesh of finite elements.

7 Claims, 2 Drawing Sheets

USING CAD DATA TO GENERATE A FINE MESH OF FINITE ELEMENTS THAT DESCRIBE A COMPONENT MODEL — S1

BASED ON THE FINE MESH, DETERMINE NATURAL OSCILLATION BEHAVIOR — S2

BASED ON NATURAL OSCILLATION BEHAVIOR, DETERMINE AREA WHOSE FINITE ELEMENTS ARE LESS DEFORMED — S3

DESCRIBE DETERMINED AREA BY A COARSER MESH OF FINITE ELEMENTS — S4

GIVE GREATER PREFERENCE TO DETERMINED AREA — S5

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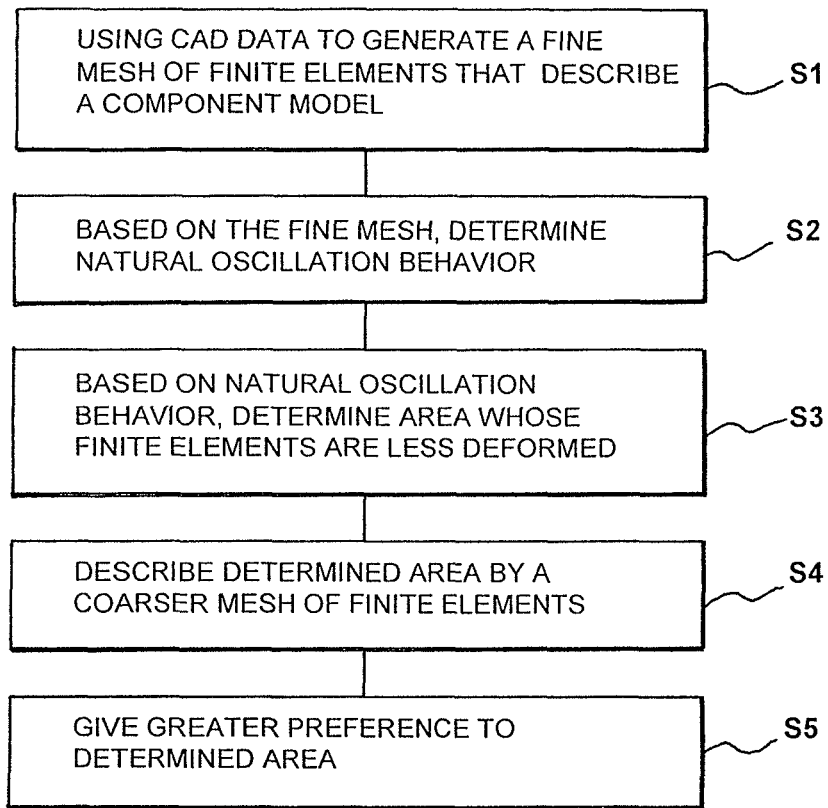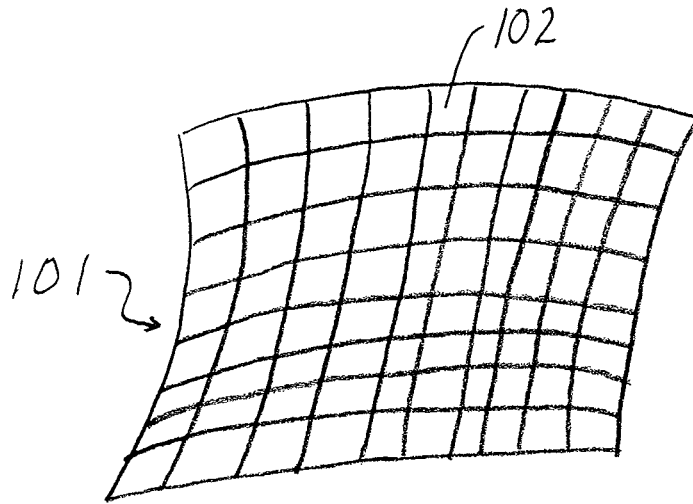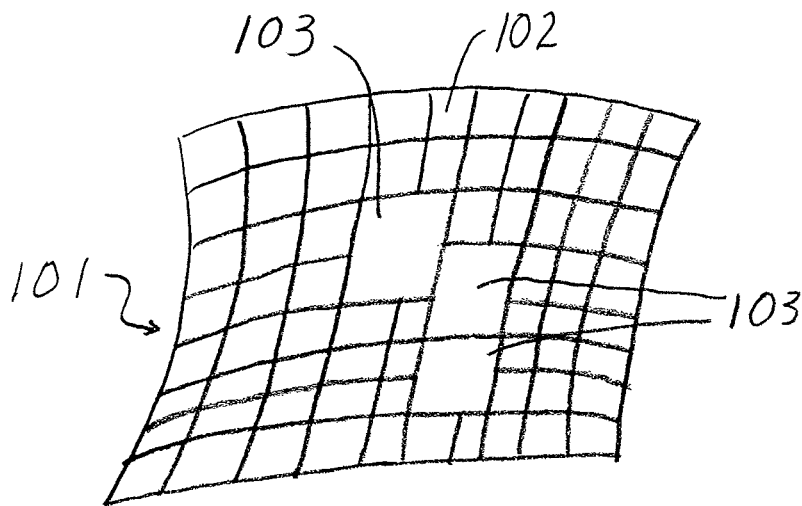
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GIVE GREATER PREFERENCE TO DETERMINED AREA — S5

Figure *1*

102

101

Fig.2

103   102

101   103

Fig.3

METHOD FOR SIMULATING A PHYSICAL PROPERTY OF A TECHNICAL STRUCTURE BY A COMPONENT MODEL

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a continuation of PCT International Application No. PCT/EP2008/001605, filed Feb. 29, 2008, which claims priority under 35 U.S.C. §119 to German Patent Application No. DE 10 2007 012 633.8, filed Mar. 16, 2007, the entire disclosures of which are herein expressly incorporated by reference.

This application contains subject matter related to U.S. application Ser. No. 12/560,101, entitled "Automatic Mesh Generation Method for Simulating a Physical Property of a Technical Structure by a Component Model," filed Sep. 15, 2009.

BACKGROUND AND SUMMARY OF THE INVENTION

The invention relates to a method and apparatus for simulating a physical property of a technical structure, such as motor or a motor part, by automatically generating a mesh of a component model, based on finite elements, and to a corresponding computer program product.

The finite element method (FEM) is a widespread computation method in engineering. As depicted in FIG. **2**, in the finite element method, a computational domain **101** is divided into a large number of small, but many, finite elements **102**. On the basis of these elements trial functions are usually defined that produce a large system of equations by way of a partial differential equation and the boundary conditions. Then the sought for results are derived from the solved system of equations.

German patent document DE 10360150 A1 discloses a method for generating the envelope of a body based on a predetermined mesh of a construction model in order to reproduce physical events on the surface of a technical system through a finite element simulation.

German patent document DE 10326228 A1, on the other hand, discloses a method for accelerating the meshing for finite element simulations of a system with multiple bodies; and U.S. Pat. No. 6,044,210 discloses a method for determining a finite element model for a structural element.

With standard software for finite element simulations, like ABAQUS, it is already possible to automatically mesh a component model (that is, to describe it by means of a plurality of finite elements). In particular, it is already possible with this standard software to adapt FE (finite element) networks to an example of application. For example, ABAQUS provides a so-called "adaptive remeshing," which describes in a first step a component model by means of a coarse FE network (synonymous with "coarse mesh of finite elements" or "coarse mesh with finite elements"). Then this network is automatically refined in an area where high mechanical stresses occur, in order to describe in a more suitable manner the component model for additional calculations. The automatic refinement is triggered as a function of the stress gradients between two FE elements. In this procedure the stress gradient between the FE elements is determined, and if it exceeds a certain value, then the network is refined at this point. As a result of the finer resolution, the stress gradient decreases.

This procedure is executed in an iterative manner until the stress gradients satisfy the established criteria. The finer the mesh, the better the mesh can usually describe the component model, the more memory space said model usually requires,

and the more computationally intensive the additional calculations or simulations, which are based on this mesh, usually are.

One object of the present invention is to provide a method for simulating a physical property of a technical structure (such as acoustic response) by automatically generating a mesh of a component model, which requires little memory space and yet suitably describes (that is, closely accords with reality) the component model. In this context, the component model may be, for example, a computer accessible construction model of any technical system or any technical structure, like a motor or a motor element or a part of a motor element.

This and other objects and advantages are achieved by the method and apparatus according to the invention, which departs from the prior art technique of proceeding from a coarse mesh, in a step-by-step manner, to a finer mesh. Instead, the technique of the present invention is precisely the reverse: to describe the component model **101** initially by means of a fine mesh (FIG. **2**), and then taking this fine mesh as a basis, to pass, in particular, step by step, at least area by area, to a coarser mesh **103**. (See FIG. **3**.)

This strategy has the advantage that a decision about which area of a component model ought to be finely meshed and which area ought to be coarsely meshed is based on a fine mesh, so that it is more reliable or leads more directly to the target than in the prior art. This approach results in a more adaptive mesh of a component model than in the prior art. Yet it can also make do with little memory space, especially because of the specifically selected areas of the coarse mesh. An additional advantage lies in the fact that an automatic mesh is quite possible, especially if the element size is small.

The present invention is based on the additional idea of pinpointing suitable areas of the component model for description by means of a coarser mesh, by analyzing the deformation behavior of the finite elements.

Other objects, advantages and novel features of the present invention will become apparent from the following detailed description of one or more preferred embodiments when considered in conjunction with the accompanying drawing.

BRIEF DESCRIPTION OF THE DRAWING

FIG. **1** is a flow chart that illustrates the steps performed by the simulation method according to the invention;

FIG. **2** shows schematically a fine mesh that characterizes a component model; and

FIG. **3** shows the mesh of FIG. **2**, which has been modified on an area-by-area basis to include a coarser mesh.

DETAILED DESCRIPTION OF THE DRAWING

As shown in FIG. **1**, for automatically generating a mesh of a predetermined component model (which is described, for example, by means of CAD data), a preferred embodiment provides that the component model **101** is described automatically, by means of a fine mesh of finite elements **102** (or with finite elements) (Step S1). (See FIG. **2**.)

Based on the fine mesh, a natural oscillation behavior of the component model is determined automatically, especially in a predetermined frequency range of, for example, 100 hertz to 3,000 hertz (Step S2). Based on the natural oscillation behavior in Step S3, at least one area of the component model is determined automatically, whose finite elements are less deformed (or are deformed in a weaker manner) than the finite elements of another area of the component model. (In particular, the finite elements are assigned by computation a weaker deformation.) The determined area is then described automatically by a coarser mesh of finite elements (Step S4), and is given more preference than before and/or than the other area of the component model (Step S5).

As a result, based on a fine mesh, the natural oscillation behavior of the component model and/or the deformation behavior of the finite elements of the component model can be determined reliably and accurately; and based on this accurate and reliable result, the areas that are less deformed can be described selectively and accurately by a coarser mesh **103**. The targeted coarser mesh of these areas has less of a negative influence on the quality of conformance, the adaptiveness, or the quality of the whole mesh of the component model, than the coarser mesh of the areas in which the finite elements are highly deformed, or than the arbitrary coarser mesh of the component model.

The mesh of the component model can therefore be mapped in a more memory-efficient manner, and can be further processed efficiently, while at the same time it can still be described sufficiently adaptively that simulations which are based on the mesh of the component model, will lead to acceptably accurate results.

For example, in the coarse mesh (or the coarser mesh) of the component model, the average volume or the average edge length of the finite elements, used for the mesh, in at least one area of the component model or in the whole component model, is larger than in the fine mesh.

The automatic description of the component model by a fine and/or coarse or coarser mesh is known, for example, from the standard software ABAQUS and, thus, can be executed. This also applies to the determination of a natural frequency or a natural oscillation mode of the natural oscillation, based on a mesh that has been automatically generated beforehand.

The determination of the deformation of finite elements is known, for example, from the standard software ABAQUS. For example, a finite element is more highly deformed than another, i) if the distances between the nodes, which belong to this finite element, change more readily, based on the calculation, than the distances between other finite elements, or ii) if the difference between the maximum volume and the minimum volume during the period of the longest natural oscillation is greater than the corresponding difference of the other finite element.

As an alternative or in addition to the deformation of the finite elements, a size that correlates to the deformation can also be used as a criterion for the next phase of coarsening the mesh. For example, based on the natural oscillation behavior, at least one area of the component model can be determined and can be described by a coarser mesh, in that its associated finite elements are assigned, in particular by computation, less elongation, less stress, a smaller elongation gradient, a smaller stress gradient, a smaller edge length change, a smaller node displacement or a smaller volume change than the finite elements in another area.

In a preferred further embodiment of the invention, based on the fine mesh, at least one fine natural oscillation of the component model (that is, a specific, fine mesh-based natural oscillation of the component model) is determined automatically: in particular, a fine natural frequency (the fine mesh-based natural frequency of the component model of a specific natural oscillation) and/or a fine natural oscillation mode (the fine mesh-based natural oscillation mode of the component model of a specific natural oscillation) is determined. Then the component model is described automatically, at least area by area, by means of a coarse mesh of finite elements, and based on the coarse mesh, at least one coarse natural oscillation of the component (a specific, coarse mesh-based natural oscillation of the component model) is determined: in particular, a coarse natural frequency (the coarse mesh-based natural frequency of the component model of a specific natural oscillation) and/or a coarse natural oscillation mode (the

coarse mesh-based natural oscillation mode of the component model of a specific natural oscillation), of the component model is determined.

Thereafter, the deviation of the coarse natural frequency from the fine natural frequency and/or the deviation of the coarse natural oscillation mode from the fine natural oscillation mode is (are) used, in particular automatically, as a measure for the quality of conformance, quality or adaptiveness of the coarse mesh and, for example, displayed.

Therefore, according to the invention, the component model **101** is initially described suitably, but memory-intensively by the fine mesh **102**, and, in so doing, the fine natural frequency (which is based thereon) is accurately determined. Then the component model is described, at least area by area, by a coarse mesh **103** with a low memory space requirement, so that the coarse natural frequency, which is based thereon, is accurately determined. Whether this coarse mesh still describes the component model in a suitable manner can then be determined based on the deviation of the coarse natural frequency from the fine natural frequency. The smaller the deviation, the more adaptive or realistic is the description of the component model, based on the coarse mesh.

Within the scope of the invention it is also clear that a plurality of natural oscillations, in particular natural frequencies, can be determined on the basis of the different meshes, and that the corresponding deviations can be used as a criterion for quality of conformance.

In an especially preferred embodiment of the invention, proceeding on the basis of a fine mesh, the component model is described automatically, step by step, area by area, by increasingly coarser meshes, especially until the deviation of the coarse natural frequency from the fine natural frequency exceeds a predetermined or user-set threshold value.

Then the deviation of the coarse natural frequency from the fine natural frequency can be used, in particular automatically, as the criterion for an abortive end of an automated mesh of a component model. Thus, proceeding on the basis of a fine mesh, the component model is described automatically step by step by an increasingly coarser mesh in at least certain areas.

Then (preferably, in addition) based on the fine mesh, the natural oscillation behavior of the component model is determined, in a predetermined frequency range. Based on the natural oscillation behavior, at least one area of the component model is determined, the finite elements of which are more severely deformed than the finite elements of another area of the component model, and the area of the component model thus determined is described by an even finer mesh of finite elements or an even finer mesh with finite elements.

The natural oscillation behavior of the component model is based preferably on an overlapping of several (that is, from two up to all) natural oscillations that lie in a predetermined frequency range. Hence, in particular the deformation behavior of the finite elements is considered for the case that the component model oscillates with an overlapping of several or all natural oscillations that lie in a predetermined frequency range.

The scope of the invention also includes a system for automatically generating a mesh of a component model with a computer that is set up in such a manner that a described method is carried out.

The scope of the invention also includes a computer program product for automatically generating a mesh of a component model. Said computer program product comprises a computer readable storage medium, on which a program is stored that enables a data processing system to carry out a described method after said program has been loaded into a memory of a data processing system.

The invention is described in detail below with reference to one example.

The invention proposes a new method that is suitable, for example, for acoustics calculation. The acoustics calculation requires FE models that readily map the natural oscillation behavior of the modeled component. This mapping is intended to be achieved with the maximum number of element sizes. The drawback of small element sizes is the plurality of elements and the related high memory space requirement of the models as well as the long computing times. For the acoustics calculation the usual approach is to construct complete motor-transmission groups that consist of a very large number of components.

The proposed method takes as a basis a fine FE network (fine mesh). This method is used to map the natural oscillation behavior as well as possible. The FE network serves as the basis and reference for additional calculations. For this model (described by the fine mesh), the natural oscillation behavior is calculated in a predetermined frequency range.

Each oscillation mode that occurs in this area generates a cyclically variable deformation in the FE model (=FE network). As a result, certain areas exhibit high elongation, other areas exhibit only low elongation. In the areas with the high elongation it is important to map the stiffness correctly using fine FE elements (small element sizes, fine mesh).

The areas of low elongation can, on the other hand, be modeled in a coarser manner. If the model is supposed to deliver good results for a frequency range, then the deformation of all modes that occur in that frequency range can be overlapped. The method, which is described below, is applied to the model with the corresponding total deformation.

The proposed method is intended to adapt the FE element size to the elongation. In this case the principle is to retain (or even to refine) a fine network in areas of high elongation, and to coarsen the FE network (mesh) in areas of low elongation. The formulaic relationship between the elongation and the FE element size can be selected by the user in a manner which is known to those skilled in the art.

According to the invention, a new calculation is performed with the network that has been modified in this way, and the results are compared with the preceding calculation with respect to the natural frequency and the natural mode (for example, tested on excursions of selected points). If the deviation of the coarsened network is below a limit to be specified, then the coarsening operation continues, according to the aforementioned method; otherwise the method is aborted, and the last valid calculation is used.

The foregoing disclosure has been set forth merely to illustrate the invention and is not intended to be limiting. Since modifications of the disclosed embodiments incorporating the spirit and substance of the invention may occur to persons skilled in the art, the invention should be construed to include everything within the scope of the appended claims and equivalents thereof.

What is claimed is:

1. A method for simulating a physical property of a component model comprising a computer accessible construction model of a technical structure, by automatically generating a mesh of the component model, said method comprising:
   initially describing, by using a processor, the component model by means of a fine mesh of finite elements;
   based on the fine mesh, determining, by using the processor, a natural oscillation behavior of the component model;
   based on the natural oscillation behavior, identifying, by using the processor, at least one area of the component model whose finite elements are less deformed than the finite elements of another area of the component model; and

modifying, by using the processor, the description of the identified area of the component model by means of a coarser mesh of finite elements,
   wherein an average volume of finite elements of the coarser mesh is larger than an average volume of finite elements of the fine mesh, or an average edge length of finite elements of the coarser mesh is larger than an average edge length of finite elements of the fine mesh.

2. The method as claimed in claim 1, wherein:
   based on the fine mesh, at least one fine natural oscillation of the component model is determined;
   the component model is further described by means of a coarse mesh of finite elements;
   based on the coarse mesh, at least one coarse natural oscillation of the component model is determined; and
   a deviation of the coarse natural oscillation from the fine natural oscillation is used as a measure for the quality of the coarse mesh.

3. The method as claimed in claim 1, wherein, proceeding from the fine mesh, the component model is described step by step by increasingly coarser meshes, until a deviation of a coarse natural oscillation from a fine natural oscillation exceeds a threshold value.

4. The method as claimed in claim 1, wherein:
   based on the natural oscillation behavior, at least one other area of the component model, the finite elements of which are deformed to a greater degree than the finite elements of yet another area of the component model, is identified; and
   the other identified area is described by a finer mesh of finite elements.

5. The method as claimed in claim 1, wherein the natural oscillation behavior is based on an overlapping of several natural oscillations that lie in a predetermined frequency range.

6. A system for simulating a physical property of a component model comprising a computer accessible construction model of a technical structure, by automatically generating a mesh of the component model, said system comprising a computer that is set up in such a manner that:
   the component model is initially described by means of a fine mesh of finite elements;
   based on the fine mesh, a natural oscillation behavior of the component model is determined;
   based on the natural oscillation behavior, at least one area of the component model is identified whose finite elements are less deformed than the finite elements of another area of the component model; and
   the description of the identified area of the component model is modified by means a coarser mesh of finite elements,
   wherein an average volume of finite elements of the coarser mesh is larger than an average volume of finite elements of the fine mesh, or an average edge length of finite elements of the coarser mesh is larger than an average edge length of finite elements of the fine mesh.

7. Computer program product for simulating a physical property of a component model comprising a computer accessible construction model of a technical structure, by automatically generating a mesh of the component model, said computer program product comprises a non-transitory computer readable storage medium, on which a program is stored that enables a data processing system, after said program has been loaded into a memory of a data processing system, such that:
   the component model is initially described by means of a fine mesh of finite elements;
   based on the fine mesh, the natural oscillation behavior of the component model is determined;

based on the natural oscillation behavior, at least one area of the component model is identified whose finite elements are less deformed than the finite elements of another area of the component model; and

the description of the identified area of the component model is modified by means of a coarser mesh of finite elements,

wherein an average volume of finite elements of the coarser mesh is larger than an average volume of finite elements of the fine mesh, or an average edge length of finite elements of the coarser mesh is larger than an average edge length of finite elements of the fine mesh.

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