Splitting Features of Rotation Shapes in the External Finite-Element Approximations Method

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Abstract

This article presents the improvement of a splitting algorithm for the External Finite-Element Approximations method (EFEAM) for 3D solid models with rotation shape. In particular, we developed an algorithm of determining a rotation axis of a 3D model. The rotation axis is found through the use of the generalized moment and the normalized cumulative angular function. Based on the rotation axis of a 3D model we improved the splitting algorithm. All section surfaces are hinged on this axis. The resultant assemblage of macroelements is more regular in the space with this improvement.

1 Introduction

Nowadays designing process of important mechanical objects is inconceivable without applying of a stress-strain state modelling software. In this area the Finite-Element Method (FEM) is considered as the most popular modern method of computer modelling. But it has difficulties in processing of big data. It is required to solve the difficult problems such as optimization and system modelling for achievement of a high operational capacity of a product. An engineer must take into account the all construction elements in a contact to each other. Here the problem of Richard Bellman's 'curse of dimensionality' seems clear. The calculation complexity leads to searching of alternative methods.

We submit for discussion the External Finite-Element Approximations Method (EFEAM) [Kur00] that is the one of such approaches. The main feature of EFEAM is that it does not require a mesh. Analysis is conducted directly on a solid CAD geometry. The method gives large freedom of approximating functions selection. Practical implementation of the method named as Procision [Dvo99, Kur00] was tested and available in the Pro/Engineer system. Despite at the advantages of Procision, it has a significant drawback - this method does not have automated tools for macroelements' generation. According to EFEAM a macroelement can have any form within a certain criteria - it must be close to the parallelepiped. Therefore, it is required the splitting of a model into subparts, the form each of which is close to the parallelepiped. In the article [Tro16] we proposed an automated algorithm for 3D models splitting into subparts. It has an iterative recursive structure. It was

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tested on the typical models selection of machine components. The results have shown the effectiveness of this approach to partition.

Many items of machine components have rotation form: gear, shaft, disk, screw, nut and etc. A common feature of such items is the rotation axis. In this article, we present the improvement of the automated splitting algorithm by introducing a special approach to handle models with rotation shape. In the first part we identify a rotation axis of a model by the generalized moment and the normalized cumulative angular function. Then we describe a new splitting process. We show results of our work for many models with different form features.

2 Rotation Axis

In this section we introduce an algorithm for the rotation axis detecting. It is provided by the use of the generalized moment function followed by calculation of the normalized cumulative angular function on it.

2.1 Generalized Moment

For the rotation axis detection of a 3D model we use the generalized moment function [Mar06]. It's a space function that has the same form features as a model. In general, for 3D surface S generaized moment M of the order of $2p$ in the direction w is:

$$M^{2p}(w) = \int\limits_{s \in S} ||\vec{s} \times \vec{w}||^{2p} ds \tag{1}$$

The generalized moment computation time depends on a model triangulation mesh that triangles are considered as ds in 1. It is time-consuming for the large number of mesh triangles. As we know, the rotation axis of a 3D model must coincide with one of the directions of principal moments of inertia and it placed in the center of mass [Sun97]. Thus it is sufficient to compute the generalized moment only for three planes, not for the whole space. These planes are placed in the center of mass and have the directions of the principal moments of inertia as normals (Fig. 1).

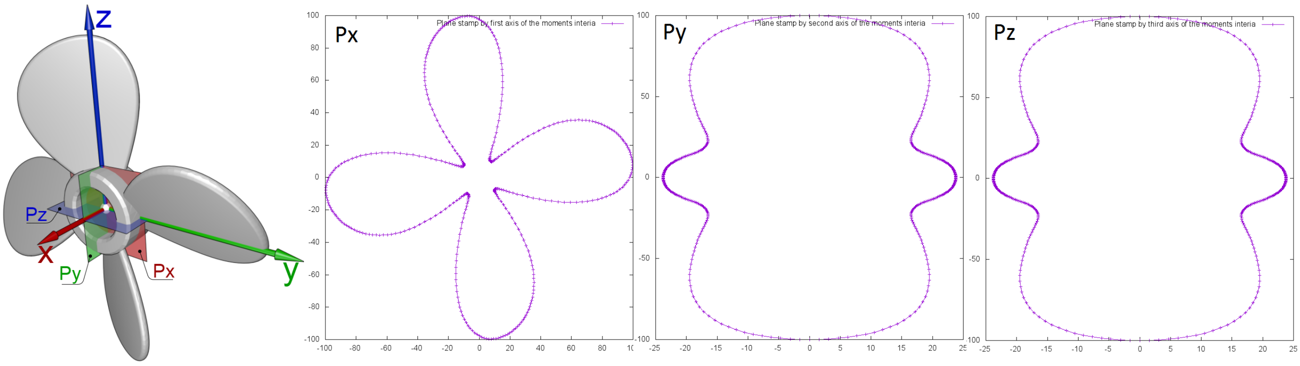

Figure 1: Generalized moment charts for the Px, Py and Pz planes with principal moments of inertia X, Y and Z as the normals

Based on our researches we can as well say that such planar chart for rotation shape in the rotation axis direction has a circular or a periodic form.

2.2 Normalized Cumulative Angular Fuction

Since the generalized moment chart can be represented as a closed plane contour, we can use the normalized cumulative angular function (NCAF) [Nix02] for the chart form recognition. This function type is used for the planar contours analysis. It has the following features: when a contour form is close to circle, the function is close to a straight line; a periodicity of the contour form directly transfers to the periodicity of function. Example on Fig. 2 demonstrates the NCAF behavior for several contours.

If NCAF has a period or insignificant deviation from a straight line then a model can be considered as a rotation shape. It's necessary to specify that the period value of NCAF is always equal to or greater than 2. It is related to the feature of the generalized moment M computation. A model mesh element ds adds value in its own direction $\vec{s}$ and in the opposite direction.

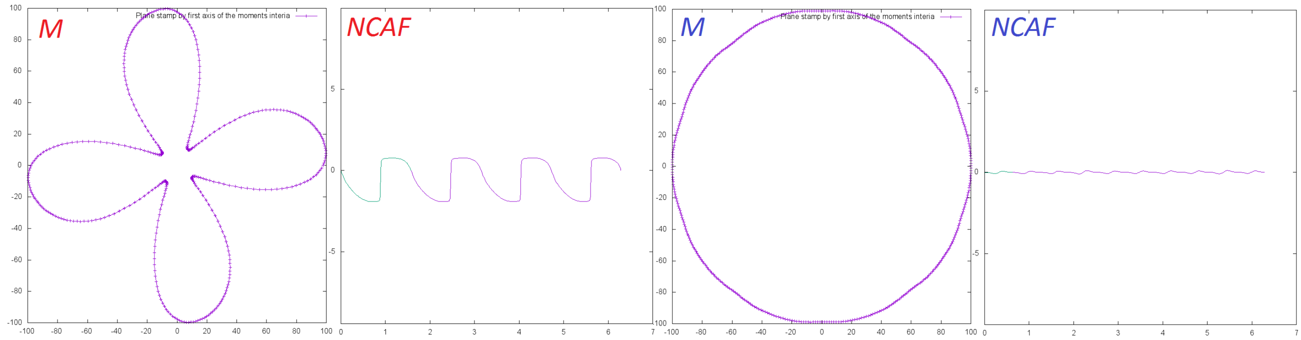

Figure 2: Examples of NCAF (on the right) for the generalized moment (M) contours

2.3 Rotation Axis Detecting

Using the directions of principal moments of inertia and the center of mass for the rotation axis location is suitable only for idealized models. Real items of machine components have various deviations. For example, the keyway on the shaft or gear has an effect on the center of mass and the rotation axis will be calculated with an error. Topological information of a model can help to solve this problem. Coaxial cylindrical and conical surfaces of a model for the most part coincide with the rotation axis. Therefore, after the rotation axis is determined by the generalized moment, it's adjusted by the axis from the topology.

Based on the above we developed an algorithm of the rotation axis detecting (Fig. 3).

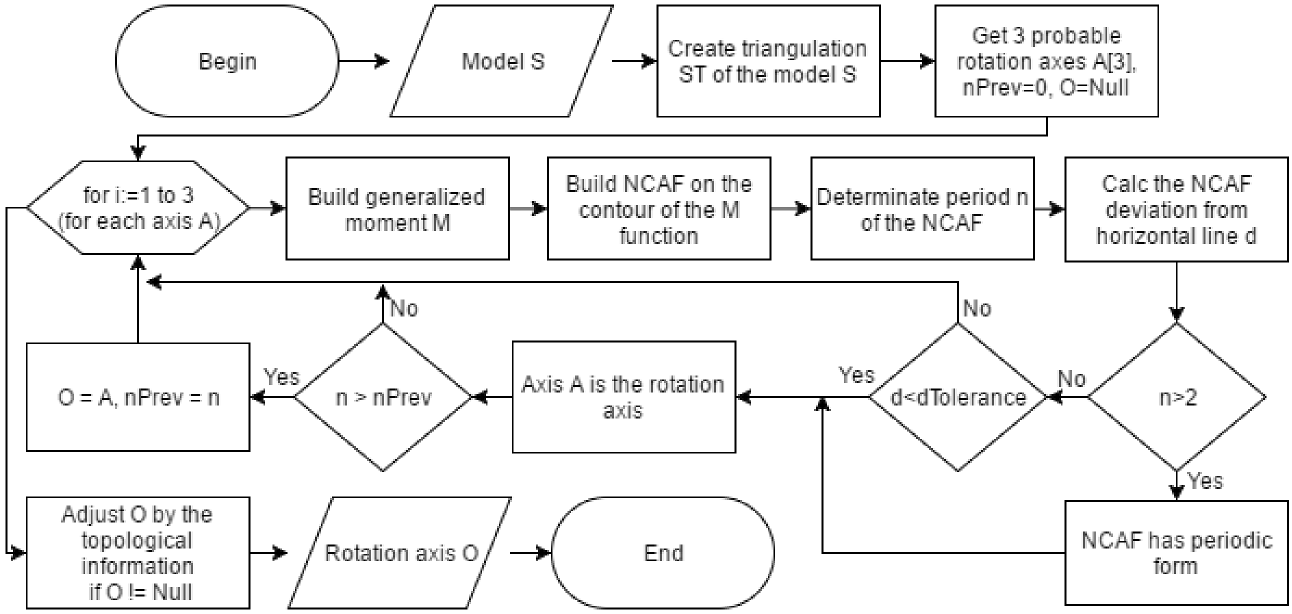

Figure 3: Rotation axis detecting algorithm

3 Splitting

3.1 Section Surfaces

With the knowledge of how to detect the rotation axis of a 3D model, we can improve the splitting process. Stand on the rotation axis, we create a polar coordinate system $O(r, \phi, z)$ in a cylindrical representation (Fig. 4). A z-axis of the coordinate system coincides with the rotation axis.

As in the standard splitting process [Tro16], for the splitting in the polar coordinate system we have three variants of a section surface for each splitting iteration. On Fig. 5 the surface 1 is a plane that perpendicular to

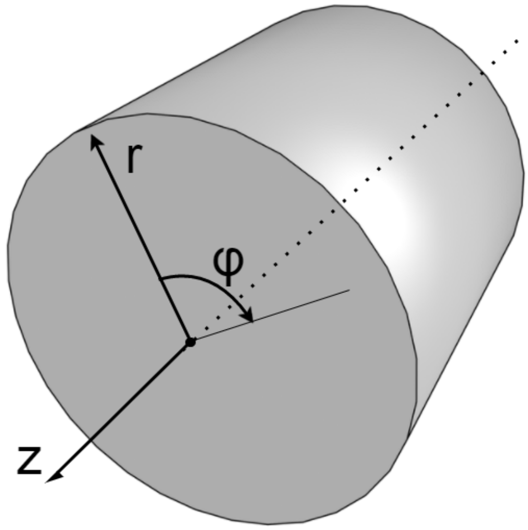

Figure 4: Location of the polar coordinate system on a model

the z-axis. The surface 2 is also a plane that contains the z-axis and positioned by the angle ϕ of the coordinate system. The cylindrical surface 3 is centered by z-axis with radial positioning by r coordinate.

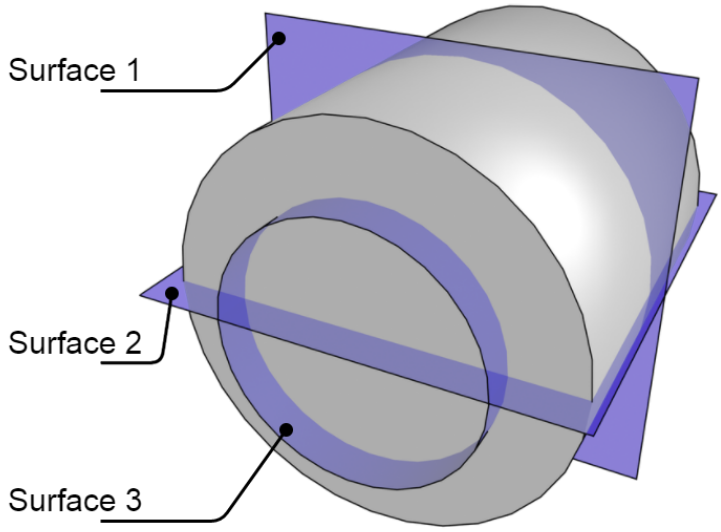

Figure 5: Section surfaces on a model

The next task is to identify the priority section surface at a particular iteration of the splitting process. There is the same rule as in the standard algorithm. We select the surface that can reduce the maximum overall size of a model. For this task we introduce a bounding cylinder of a model. It is hinged on the rotation axis and might have an entire form or a sector only. The bounding cylinder has three key parameters (Fig. 6): height h, thickness t and sector angle α. But due to the fact that in this case the surfaces selection rule operates with no equivalent values (angle and distance), the selection strategy will be different. For their comparison we transform the angular value ϕ into linear, i.e. in the arc length $L = \phi \times R$ by the outer radius R of the bounding cylinder. Then the selection of the priority section surface submits the following rule: if the maximum of three values is h then we select the surface 1; is the arc length L then the surface 2; is the thickness t then the surface 3.

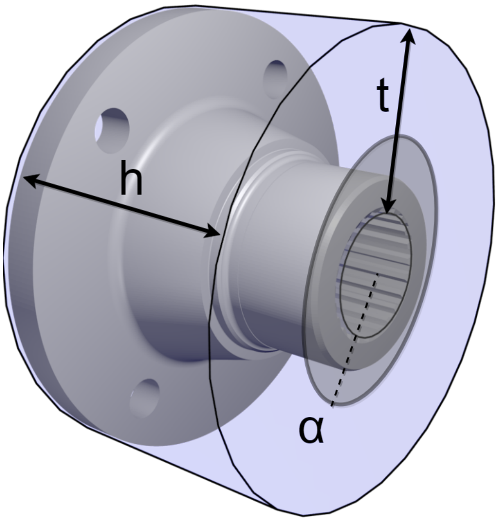

Figure 6: Bounding cylinder parameters

3.2 Splitting Algorithm

Based on the bounding cylinder and the selection rule of the priority section surface we introduce the new splitting algorithm (Fig. 7).

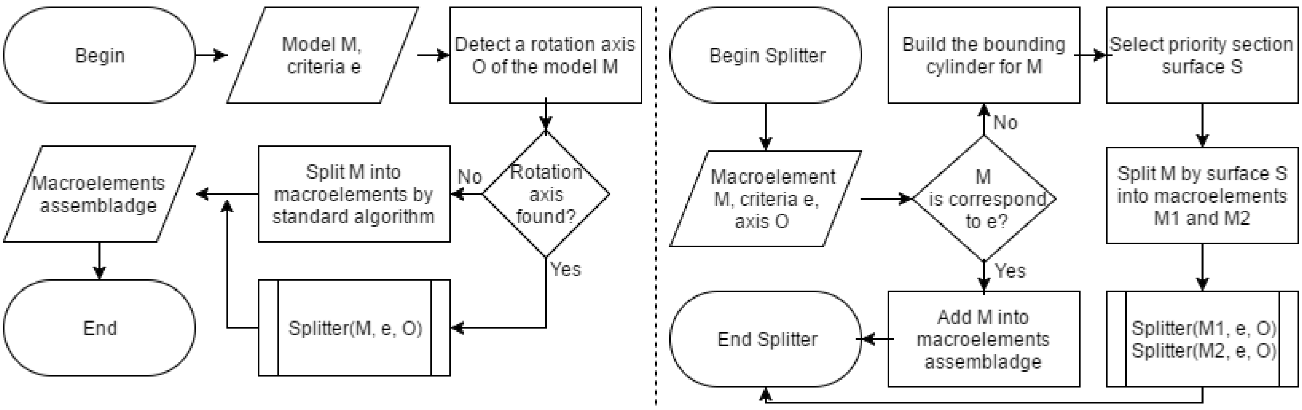

Figure 7: Splitting algorithm

4 Results

The splitting algorithm implementation has been tested on a set of mechanical components items. The results confirmed the expected improvement of the qualitative characteristics of the macroelements' assemblage. Their distribution on a model is more regular and in a greater degree describes model features. The splitting results of several 3D models are presented in the Fig. 8. The splitting results of the standard algorithm are shown on the left and the results of its improved version are on the right.

As for performance, the new splitting method requires in 1.5-3 times more time for execution. Firstly, the reason for that is the rotation axis detecting. Secondly, it is the computation of the bounding cylinder on each splitting iteration. Thirdly, in some cases the splitting is provided by quadric section surface. However, the generalized moment calculation takes most of the time in the rotation axis detecting. It depends on the size of the triangulation mesh. But the algorithm structure allows the paralleling computation. It might increase the performace.

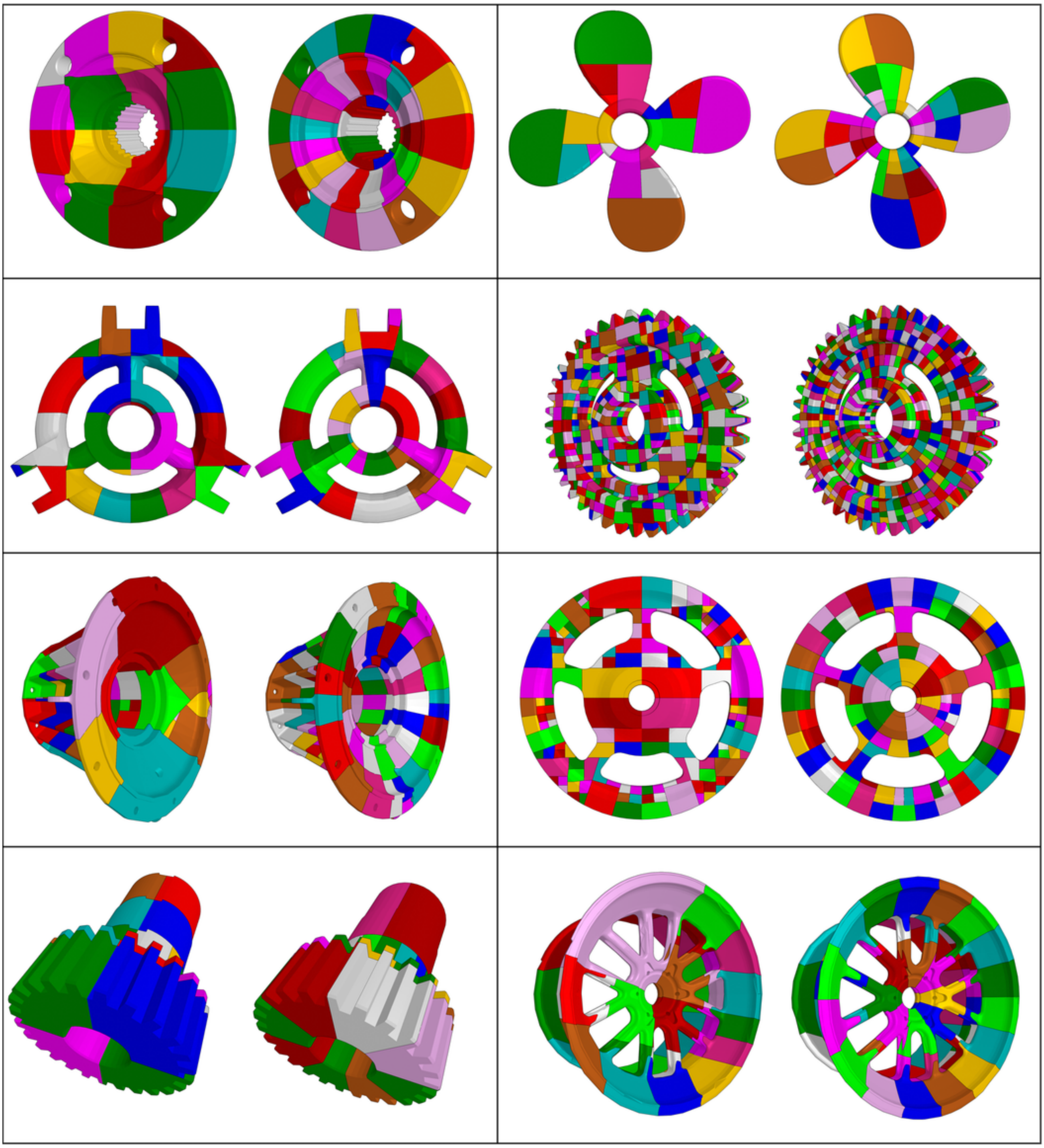

Figure 8: Splitting results. The results of the standard algorithm are shown on the left and the results of its improved version are on the right.

5 Conclusions

We have presented the new splitting algorithm for the External Finite-Element Approximations Method for 3D models with rotation shape. The results showed that the developed algorithms are operative. The macroelements' assemblage has more regular splitting than before its improvement. We use the generalized moment and the normal cumulative angular function for the rotation axis detecting. The generalized moment is computed only for the planes of candidate axes. This approach allows to detect the rotation axis quickly and with good accuracy.

Future Work

Low splitting performance can be improved by parallelization of the computational process. Both the splitting algorithm and the rotation axis detecting algorithm have this opportunity. In the future, we are going to move from the solid-state splitting to polygonal one. It also can increase the computation performance.

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