Magnetic-Structural Parallel Coupled Analysis of Simplified MRI model with Mesh Smoothing

Shin-ichiro Sugimoto [1], Hideki Fujii [1], Shunji Kataoka [1] and Shinobu Yoshimura [1]

[1] The University of Tokyo, Japan

1 Introduction

There are various general-purpose computational mechanics systems for simple phenomenon analysis such as fluid analysis, structural analysis, heat conduction analysis, magnetic field analysis, and so on. However, because most actual phenomena are mutual related compound phenomena with more than two kinds of phenomena, the coupled analysis that contains the mutual related compound phenomena is required for obtaining characteristics of the actual phenomena in detail. Therefore, we are developing general-purpose coupled analysis systems which integrate more than two kinds of solvers. In this study, we consider to develop a general purpose Magnetic-Structural coupled analysis system that is particularly useful to a medical Magnetic Resonance Imaging (MRI) equipment, where the vibrations of the yoke, due to the electromagnetic force generated by the gradient coil.

Moreover, considering recent numerical analysis, a computational object like the MRI is a highly complicated mechanical object. In addition, subdivision of the mesh is performed for the improvement of accuracy. Therefore, large-scale computations are increasingly important. To reply this requirement, we will use solvers that adopt Hierarchical Domain Decomposition Method (HDDM) [1][2] that achievements to solve problems with over 1 billion Degrees of Freedom (DOF). As a solver for magnetic analysis, ADVENTURE_Magnetic module is used [3][4]. And as a solver for structural analysis, ADVENTURE_Solid module is used [2][5]. These modules are finite element analysis solvers designed in the ADVENTURE Project [6] to perform the magnetic analysis and the structural analysis.

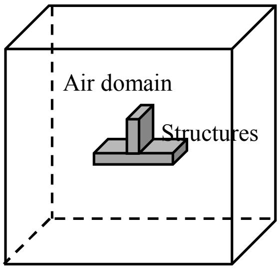
In the previous study, we have considered the magnetic-structural coupled analysis without the mesh smoothing [7]. Therefore, we were able to handle only very small vibration. In this paper, in order to handle a larger vibration, the mesh smoothing is introduced into the magnetic-structural coupled analysis system. As the mesh smoothing method, we consider the Jacobian-based stiffening [8][9].

2 Magnetic-Structural Coupled Analysis with Mesh Smoothing

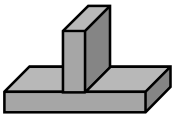
In the previous study, the magnetic-structural tow-way coupled static analysis was performed in the following procedure [7]:

a) Electromagnetic force that works on the structures is obtained by the magnetic field analysis of the structures and the air domain (Fig. 1 (a)).
b) Structural displacement is obtained by the structural analysis of the structures (Fig. 1 (b)).
c) The mesh for the magnetic field analysis is modified with the displacement of the structures.
d) The magnetic field analysis is performed again.
e) The structural analysis is performed again.
f) If difference of the displacement between new one and previous one is enough small, this procedure is finished. Otherwise, this procedure returns to c).

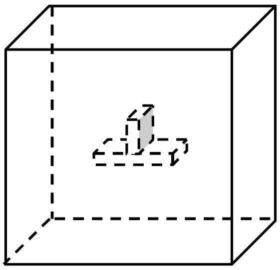
Because only the displacement of the structures is considered in this procedure, elements in the air domain that is on boundaries of the structures and the air domain are crushed or reversed when the structural displacement is large. Therefore, we were able to handle only very small vibration.



(a) Field for the magnetic field analysis.



(b) Field for the structural analysis.



(c) Field for the mesh smoothing.

Fig. 1. Fields for analyses.

In order to handle a large vibration, the mesh smoothing is introduced. In this paper, we consider the Jacobian-based stiffening [8][9] as the mesh smoothing method. In this method, we consider the linear elasticity analysis of the air domain (Fig. 1 (c)). The structural displacements on the boundaries of the structures and the air domain are given as the Dirichlet boundary conditions. Furthermore, to make this method more robust, selective mesh deformation based on the element sizes is implemented. Generally, the element sizes around the structures that may move greatly are small. On the other hand, they become large as they become far from the structures. If small elements around the structures are deformed, because they are crushed or mesh quality turns worse, the coupled analysis fails easily. Therefore, the Young's modulus is made large as element size becomes small. Hereby, even if small elements move greatly, it is hard to deform them. In this paper, we assume the reciprocal number of the volume of the element the Young's modulus.

And now, new procedure is as follows:

a) Electromagnetic force that works on the structures is obtained by the magnetic field analysis of the structures and the air domain (Fig. 1 (a)).
b) Structural displacement is obtained by the structural analysis of the structures (Fig. 1 (b)).
c) Mesh smoothing of the air domain (Fig. 1 (c)).
d) The mesh for the magnetic field analysis is modified with the displacements of the structures and the air domain.
e) The magnetic field analysis is performed again.
f) The structural analysis is performed again.
g) If difference of the displacement between new one and previous one is enough small, this procedure is finished. Otherwise, this procedure returns to c).

3 Numerical Result with Simplified Model

To verify our method basically, a simplified model (Fig. 2 (a)) is considered. This model consists of a plate and a permanent magnet. The plate is transformed by electromagnetic force of the permanent magnet.

Fig. 3 shows the transformation of the plate. By introduction of the mesh smoothing, even if the displacement is larger than element sizes, we were able to obtain actual solutions without failure of analysis.

4 Conclusion

In this paper, we have introduced the mesh smoothing to the magnetic-structural coupled analysis. In the future work, we will adopt this system to the MRI model [10].

Acknowledgements

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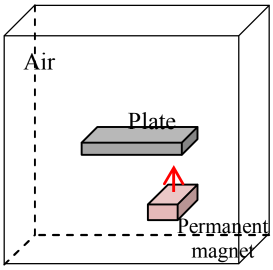
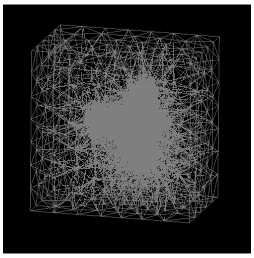
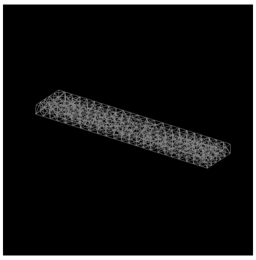


(a) Simplified model.



(b) Mesh for the magnetic field analysis.



(c) Mesh for the structural analysis.

Fig. 2. Simplified model.

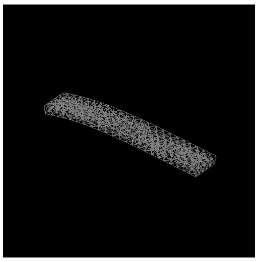


Fig. 3. Transformation of the plate (x100).