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Development of a Finite Element Data Exchange System for chain simulation of manufacturing processes

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ABSTRACT

A Finite Element Data Exchange System (FEDES) is developed to transfer and map finite element analysis (FEA) data between different FE solvers and meshes. Six commercial FE codes (ABAQUS, ANSYS, DEFORM, MSC.MARC, MORFEO and VULCAN) are incorporated in FEDES. Four mapping techniques are developed and embedded in FEDES which allow the data mapping between meshes with different element types and densities. The algorithms of the mapping techniques are described and compared for 2D and 3D models. The design and capabilities of FEDES are also described. Results from the data transfer and mapping between different FE simulations are presented and discussed. Two manufacturing chains are simulated using FEDES in this paper. The first manufacturing chain is simulated on a parallelepiped geometry including casting, forging and heat treatment processes. The second manufacturing chain is simulated on an aero-engine vane component including metal deposition, welding, heat treatment, machining and shot-peening processes. The development of FEDES demonstrates an integrated simulation platform for modelling manufacturing chains of processes using different FE solvers and meshes.

1. Introduction

Nowadays, the FEM has been widely used for modelling and simulation of a variety of applications related to aerospace, automotive, energy and other industries. A number of finite element packages (FEPs) have been developed for linear and nonlinear structural analysis, fluid flow, solid–fluid interaction, heat conduction, flow through porous media, and coupled physical problems [1]. Each FEP has its advantages and strengths in different fields which makes it the first option among modellers and analysts. Producing high quality final products in a manufacturing chain might require involvement of many manufacturing processes. Simulating each manufacturing process requires a close investigation for the most appropriate FEP in terms of accuracy, computational time and user-friendly interface. This means that for simulating a chain of manufacturing processes, many different FEPs can be involved. Also, different element types can be found to be more suitable for different manufacturing processes and geometrical complexities. The generation of residual stresses, plastic deformations, geometrical distortions, etc., after each simulated process requires FEA data transfer from one FEP to another and mapping FEA data between meshes with different element types and densities. This issue raises the need for creating a generic software platform for transferring and mapping FEA data among different FEPs and meshes with different element types and densities.

The challenges involved in the simulation of manufacturing chains using FE techniques have been also addressed by other researchers. Fernandes and Martins [2] have developed an algorithm including extraction of the basic geometrical features, contraction of the core mesh, generation of a boundary mesh linking the core with the surface of the workpiece, applications of smoothing procedures to edges and transfer of field variables from the old to the new mesh. Dureisseix and Bavestrello [3] have transferred information between non-matching FE meshes. The work concerns a transfer of FE variables defined at the integration points of the meshes by using only local element-by-element matrices. Luo [4] has proposed nearest-nodes finite element method where the finite elements have been used only for numerical integration while the shape functions are constructed by using a set of nodes that are the nearest to a concerned quadrature point. A local multivariate Lagrange interpolation method has been used to construct the shape function. Hyun and Lindgren [5] have demonstrated different meshing capabilities when simulating a chain of manufacturing processes by using an in-house FE code. A billet made of stainless steel SS316L and meshed with 2D 4 or 8 node quadrilateral elements has been forged, heat treated and cut. Pietrzyk et al.

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[6] have performed a manufacturing chain simulation of the M14 bolt which involves heat treatment, drawing, multistep forging, machining and rolling. Forge 2005 FE code has been used to carry out the manufacturing chain simulation.

Jahansson et al. [7] have developed a system to manage the simulation information of manufacturing processes, such as mesh information, boundary conditions and process parameters. The system has been used to predict simulation of the cutting process using mesh information and process parameters from the database which is embedded in the system that uses a conceptual EXPRESS information modelling language and the STEP Part 21 standards. Charles et al. [8] have presented an implementation of data exchange standards in the aeronautics industry. STEP AP209 standard has been used for exchanging FEA data. The development of a translator from STEP AP209 to SAMCEF (commercial FE solver) has been carried out and evaluated on an aircraft engine component. Zeng et al. [9] have addressed the challenges with a knowledge-based FEA modelling method called ZAP that consists of three stepping-stone information models and the mapping processes between these models. The information and knowledge of a typical FEA modelling process have been explicitly captured in semantically rich information models. Dolenc [10] has developed a component-oriented software targeted for structural analysis using the FEM where the Extensible Markup Language (XML) has been used as a file format for data exchange between different software systems.

Despite the conducted research there are still knowledge gaps in simulation of manufacturing chains using the FEM. For example, the manufacturing chains have been mainly simulated with identical meshes in the same FEP. This can lead to some restrictions in situations where a manufacturing process cannot be simulated with the corresponding FE code or the element type is not suitable for the corresponding process. Some research in FEA data mapping and data transfer between non-matching meshes has been performed for simple benchmarks and limited number of FE codes. The simulation of manufacturing chains using the FEM requires the development of a user-friendly and robust software system supported by mathematical algorithms for performing the FEA data transfer and mapping between non-matching meshes and FEPs. Development of such a system can be beneficial for the simulation of a variety of manufacturing chains involved in industry. The system can also be beneficial for optimizations and design of manufacturing chains. The objectives of this study are to develop a generic software platform which has the capability to transfer and map FEA data between different FEPs and meshes with different element types and densities. The aim of this system is to enable the simulation of manufacturing chains using the FEM. Developing a user-friendly Graphic User Interface (GUI) is an essential part of the system in order to make it accessible for users in industry and research organizations.

2. Interpolation techniques

Four interpolation techniques are incorporated in FEDES to map FEA data between different meshes; namely nearest point method, distance method using field of points, distance method using elements and method using the element shape function. All four techniques can be used for mapping FEA data at nodal and integration points of the new mesh by using the nodal results from the old mesh.

2.1. Method 1: Nearest point method

This is the simplest method for interpolating FEA data between two meshes with different element types and densities. Practically, it can be used for mapping FEA data from refined to coarse meshes where it can provide accurate results and fast calculations. The opposite variant can also be achieved but it provides results with lower accuracy. Fig. 1a shows a quarter of perforated plate with two different meshes. All nodes in mesh 1 contain result FEA data (stresses, strains, displacements, etc.). The goal is to map data into all nodes in mesh 2 from mesh 1. This method takes each node from mesh 2 (e.g. node M) and searches for the closest node in mesh 1 (e.g. node N). When the closest node from mesh 1 is located then the corresponding node form mesh 2 assigns the data from that node. The search criterion is performed by defining the minimum distance between node M and all nodes from mesh 1. The distances between node M and nodes N_i can be given by.

$$d_i = \sqrt{(N_i(x) - M(x))^2 + (N_i(y) - M(y))^2 + (N_i(z) - M(z))^2}, i = 1, 2, \ldots, n \quad (1)$$

where n is the number of nodes in mesh 1, $M(x)$ is the x coordinate of node M, $M(y)$ is the y coordinate of node M, $M(z)$ is the z coordinate of node M, $N_i(x)$ is the x coordinates of node N_i, $N_i(y)$ is the y coordinates of node N_i, $N_i(z)$ is the z coordinates of node N_i and d_i is the distances between node N_i and M.

2.2. Method 2: Distance method using field of points

This method can be used for mapping FEA data from refined to coarse meshes with different element types and densities and the other way around. This method performs the interpolation by using a field of points rather than a single point. Fig. 1b shows the location of node M which is transferred from mesh 2 to mesh 1. Node M in mesh 1 is used as the origin of a new coordinate system in mesh 1 with x and y axis. This coordinate system is defined by four quadrants in 2D models and eight quadrants in 3D models. The nearest nodes to node M for each quadrant are identified. In

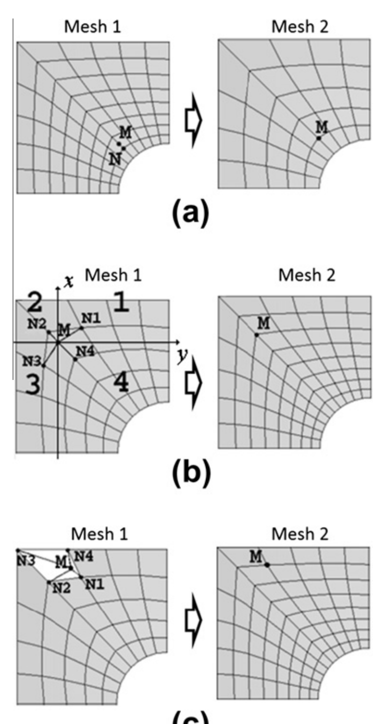

Fig. 1. Schematic of FEA data transfer between non-matching meshes using the: (a) nearest point method; (b) distance method using field of points; (c) distance method using elements.