Hybrid Parallel Meshless Algorithm for Electromagnetic Applications

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***Abstract* — This work focuses on a hybrid computational design of the Element-free Galerkin Method. The design is based on two kinds of parallel computing: Message Passing Interface and Open Multiprocessing. The serial meshless algorithm for the movement modeling of induction machines is presented and parallel processing opportunities are identified and discussed. Based on this analysis a hybrid parallel algorithm is proposed.**

***Index Terms*—Parallel Programming, Mesh Free Methods, Element-free Galerkin Method, MPI, OpenMP.**

I. Introduction

Meshless Methods, also called Meshfree Methods, are a class of numerical methods to solve partial differential equations. The main characteristic of these methods is that they do not need a mesh like the one used in the Finite Element Method. In this sense, meshless methods are very useful for modeling moving structures, such as electric machines, without a remeshing process [1]. Nevertheless, the advantage of avoiding a mesh does not come cheaply; this class of method is much more computationally expensive than the finite element method. So, for large problems, such as electric machines meshless models, an efficient parallel design is very useful.

In this work an analysis of the Element-free Galerkin Method (EFGM) algorithm is done, a serial program profile is obtained and opportunities for parallelization are identified. Based on this analysis, a hybrid parallel design making use of Message Passing Interface (MPI) and Open Multiprocessing (OpenMP) is presented.

II. Element-free Galerkin Method

In the Element-free Galerkin Method the moving least squares are employed for the construction of the shape functions, the Galerkin weak form is employed to develop the system of equations and a set of background cells is required to carry out the numerical integration of weak form [2-4].

In this method a local approximation function is given by

$$u^h(\mathbf{x}) = \sum_{I=1}^{n} \phi_I(\mathbf{x}) u_I \tag{1}$$

where $\phi_I(\mathbf{x})$ is the MLS shape function at node *I*.

It is important to note that MLS uses the concept of influence domain, which means the region where each node has influence upon. In this sense "*n"* on (1) represents the number of nodes that have influence on point **X.** In other words there are "*n*" nodes in the support domain of **X.**

III. The Induction Machine Model

A three-phase, 4 poles, 50Hz, 2 HP squirrel-cage induction motor is modeled. Due to symmetry considerations and using anti-periodic boundary conditions, only ¼ of it needs to be modeled [5]. The original motor has a total of 36 stator slots with 44 Amp*Turns. There are 28 slots on the rotor filled with aluminum (σ = 34.45 MS/m) with 100mm depth [1].

After applying the Element-Free Galerkin Method, a set of matrix equations is obtained:

$$\overset{\text{AKT}}{\begin{bmatrix} \mathbf{K} + \mathbf{N}/\Delta\mathbf{t} & -\mathbf{P} & \mathbf{0} \\ \mathbf{Q}/\Delta\mathbf{t} & \mathbf{C_3} & \mathbf{R} \\ \mathbf{0} & \mathbf{C_1^T C_1} & \mathbf{C_2} \end{bmatrix}} \begin{bmatrix} \mathbf{A(t+\Delta t)} \\ \mathbf{U_t} \\ \mathbf{I_t} \end{bmatrix} = \overset{\text{FORCE VECTOR}}{\begin{bmatrix} \left(\mathbf{NA(t)}/\Delta\mathbf{t}\right) + \mathbf{J(t+\Delta t)} \\ \mathbf{Q\,A(t)}/\Delta\mathbf{t} \\ \mathbf{0} \end{bmatrix}} \tag{2}$$

where **A** is the magnetic vector potential, **J** is the current density source related to phases A, B and C, $\mathbf{U_t}$ is the voltage on the bar terminals and $\mathbf{I_t}$ is the current on them, K is the stiffness matrix, **N** is the matrix related to shape functions, $\mathbf{C_1}$ $\mathbf{C_2}$ and $\mathbf{C_3}$ are auxiliary matrix obtained by Kirchhoff's laws and **P** and **Q** are matrices related to the rotor bars [1].

The movement modeling of electric machines is a complex process for other numerical methods, but with EFGM it basically consists of the rotation of nodes located at the rotor region [1].

An example of the resulting magnetic flux distribution obtained with (2) is shown in Fig. 1.

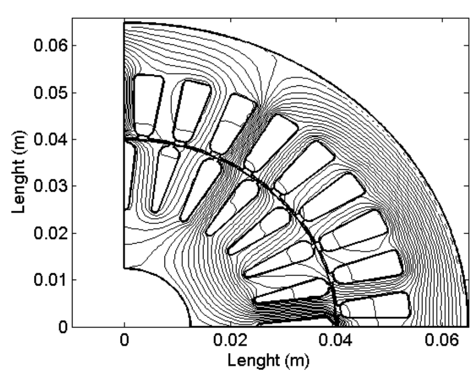

Fig. 1. Resulting magnetic flux distribution

IV. EFGM FLUXOGRAM

The EFGM fluxogram that implements the meshless model of time domain moving induction machine described in sections II and III is presented in Fig. 2. Note that the main flow passes through the integration over the entire domain represented by the box “Loop over background cells”. This characteristic in the flow allows a domain division as presented in Fig. 3 and the use of MPI.

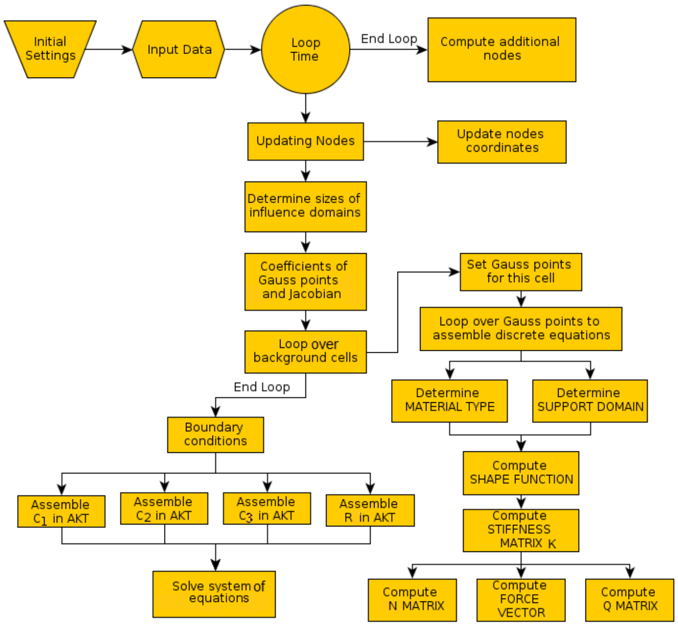

Fig. 2. EFGM fluxogram for an induction machine meshless model

V. PARALLEL STRATEGY

The parallel strategy is based on separating regions where MPI is more suitable and regions where OpenMP is more efficient [6]. A natural MPI application is in domain decomposition, where the domain is subdivided and mapped for each cluster’s node (Fig. 3). In this figure the subdomains were divided in regions having the same area. Because meshless methods use the concept of influence domain, dashed line regions were included, where nodes of neighboring regions can be reached by that computer .

After domain division, each node or computer assumes a set of tasks as shown in Fig. 4. Theses nodes are multiprocessor computers with four or six cores each, suitable for multithreading operations with OpenMP. Tasks such as determination of material type and support domain use a KDtree data structure and are relatively computational expensive.

Other important candidates to be parallelized are the linear system solver, where a significant part of computation time is spent, and the shape function calculation that is significantly more complex than in finite element method. In the case of system solver, a parallel unsymmetric multifrontal sparse Lu factorization algorithm will be used. The non parallel version of this solver was used in the serial program with good performance.

Finally, all expensive loops and routines present at OpenMP region (Fig. 5) are parallelized. A complete analysis and program profile will be presented in the extended version of this paper.

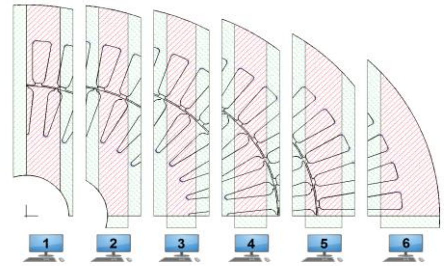

Fig. 3. Domain division and node mapping

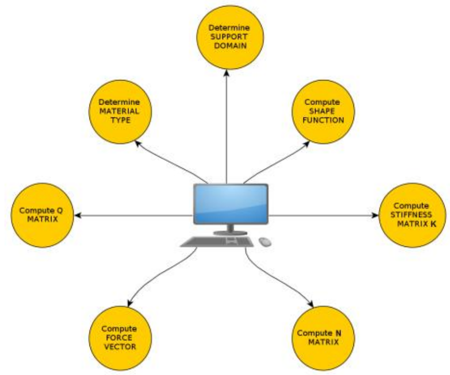

Fig. 4. Tasks mapped to each node

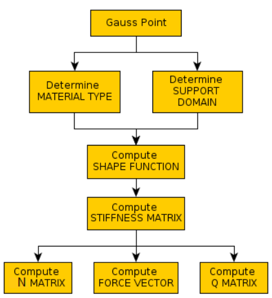

Fig. 5. Fluxogram’s region where OpenMP is applied

VI. ACKNOWLEDGEMENT

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