# Possibilities of Parallel Computing in the Finite Element Analysis of Industrial Forming Processes

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**Abstract.** The paper presents an overview of the possibilities of parallel computing for the analysis of industrial forming processes using the finite element method. The theoretical and computational aspects of the various finite element formulations are presented in some detail as well as the different strategies for parallelization of the solver, the mesh generation, the error simulation and the mesh adaption modules. Some examples of parallel analysis of powder compaction and sheet stamping processes using parallel finite element codes developed at CIMNE are finally presented.

## 1 Introduction

In the last decade, computer applications aimed at facilitating and improving forming processes in the manufacturing industry have been honed from tools used only by specialised reseachers to everyday devices for use from the shopfloor to the designers desk [1-7]. The nature of these new computer-based tools and methodologies is such that the software programs themselves and the expertise needed to use them are not specific to a single forming process.

The potential applications and technical benefits of computer based systems for the forming industry have been explicitly recognised in the report "Computer-Aided Engineering for Metal Forming" published by the EC in 1995 [8]. In this report the state of the research in Europe, USA and the rest of the world is analysed together with a study of the market size and a description of the main companies and software products.

It should not be however forgotten that the development of reliable computational procedures to predict the behaviour of deformation processes during forming operations has encountered many serious obstacles. Together with the nonlinearity of the material, other important effects like the unsteady nature of the process, the large magnitude of the strains involved and the importance of contact and frictional effects at the tool-material interfaces make the study of forming processes so complex that its analysis justifies the use of sophisticated numerical techniques such as the finite element method [6] and usually leads to huge computer requirements.

The ultimate aim of computational procedures is to advance in the design and manufacturing of metal, plastic and glass based products, hereby bringing about quantitative improvements in the competitive state of manufacturing enterprises. The fundamental numerical methods developed form only a part of the simulation requirements of the manufacturing industry and a comprehensive support system would need additional facilities. In particular, the important aspects of a CAD link and access to a material and process database are necessary for computational tools to be considered useful for routine industrial applications. Additionally, software modules which assess the "fitness-for purpose" of the industrial codes are also essential.

It is also important that such computational tools can be implemented on relatively low cost hardware platforms (such as the PC networks) which is considered essential for acceptance of the methodology within general manufacturing industries.

Industrial forming processes such as sheet stamping, rolling, extrusion, molding, etc., involve the continuous deformation of the material in time. The equations of motion of this transient problem can be written in terms of the displacements of the deformed material points measured from an appropriate reference configuration (displacement approach), or else in terms of their velocities at each moving configuration (flow approach).

Both, displacement and flow approaches can make use of sophisticated elasto-plastic/viscoplastic material models. Alternatively by neglecting elastic effects simpler rigid-plastic/viscoplastic models can be employed. Finally the equations of motion can be of quasi-static type leading to the so called *implicit* finite element codes or else incorporate dynamic inertia effects, this being the basis of the *explicit dynamic* codes.

Despite recent advances in enhancing the overall efficiency of implicit and explicit finite element codes, the numerical simulation of forming processes of industrial size is still today a formidable task which generally requires excessive computing effort to be efficiently applicable as an everyday design tool. The need for improving the efficiency of existing serial codes via parallelization is therefore obvious. The opportunity and necessity of such a development is precisely the goal of much current research which aims to fill this gap and release parallelized codes for analysis and design of industrial forming problems in clusters of PC's and workstations affordable by SME's in the manufacturing sector.

This paper aims at presenting an overview of the possibilities of enhancing current finite element based computational procedures for analysis and design of industrial forming processes by means of parallel computing techniques. The layout of the paper is the following. In next section the crucial steps in the parallelization of a finite element code for analysis of industrial forming processes are listed. The following sections are devoted to the description of the quasi-static and explicit dynamic finite element solution techniques. Here the possibilities of their parallelization in different computer architectures are discussed. The paper follows by describing different alternatives for parallel mesh generation and parallel mesh adaption using error estimation procedures. In the last part of the paper some examples of application of implicit and explicit finite element