SIMULATION OF COUPLED ELECTROMAGNETIC-MECHANICAL SHEET FORMING

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Abstract. *The finite element method has characteristics that do it a powerful tool to solve electromagnetic problems. In this paper low frequency industrial electromagnetic-mechanical forming applications of code based in the regularization of Maxwell equations will be presented. Analytic and experimental validations will be described. Standard and specific developments, soported on GID platform, are described too.*

1 INTRODUCTION

Electromagnetic Forming (EMF) is a metal working process that relies on the use of electromagnetic forces to deform metallic workpieces at high speeds. The EMF pieces can be used alone or combined with the usual mechanic methods. In this process, a transient electric current is induced in a coil using a capacitor bank and high-speed switches. This current induces a magnetic field that penetrates the nearly conductive workpiece where an eddy current is generated. The magnetic field, together with the eddy current, induces Lorentz forces that drive the deformation of the workpiece. In an EMF process, the material can achieve velocities in the order of 100 m/s in less that 0.1 ms. The dynamics of this event, including die impact, enhance the formability of the workpiece and reduce springback [i].

With the current state of the art of software, the EMF problems consist in two separate analysis. CIMNE works is working into coupling the two analysis in only one process.

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2 ELECTROMAGNETIC PROBLEM

ERMES is a FEM Electromagnetic code that solves Ecuaciones de Maxwell Regularizadas en Presencia de Singularidades [i][ii]. Its pre and postprocessor resources are based on the GID platform (see ERMES bar in fig.1 and two of the menus in fig. 2).

Figure 1: ERMES icons Bar in GiD platform

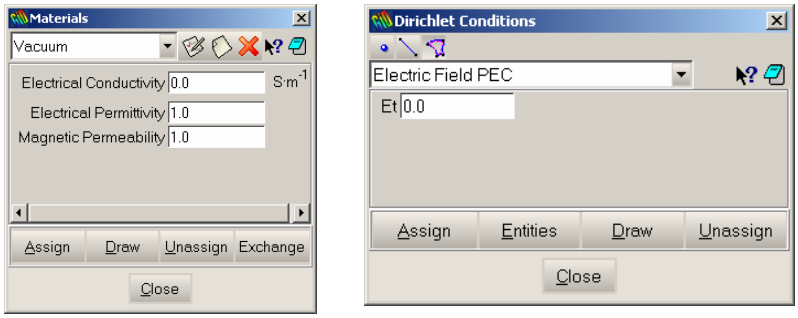
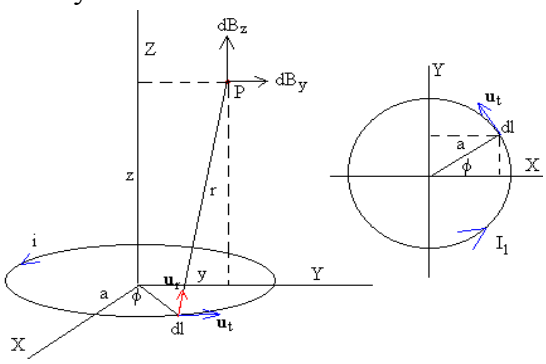


Fig. 2: Input material data and Dirichlet conditions

In order to validate this electromagnetic code, which is in development, the numerically simulated model with the one spire analytic solution was compared. The formulations of the analytic model are:



$$Bz = \frac{\mu_0}{2\cdot\pi}\cdot i\cdot a\cdot\int_{\Pi}^{0}\frac{-(a-y\cdot\cos(\theta))}{(a^2+y^2+z^2-2\cdot a\cdot y\cdot\cos(\theta))^{3/2}}d\theta \quad (1)$$

$$By = \frac{\mu_0}{2\cdot\pi}\cdot i\cdot a\cdot z\cdot\int_{\Pi}^{0}\frac{-\cos(\theta)}{(a^2+y^2+z^2-2\cdot a\cdot y\cdot\cos(\theta))^{3/2}}d\theta \quad (2)$$

$$Hz = \frac{Bz}{\mu_0} \qquad Hy = \frac{By}{\mu_0}$$

$$H = \sqrt{Hz^2 + Hy^2} \quad (3)$$

The expressions (1) and (2) have been solved with the explicit mathematical program Mathcad®.

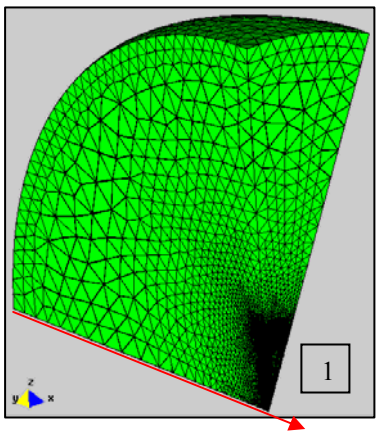


Fig. 3: Simulation mesh

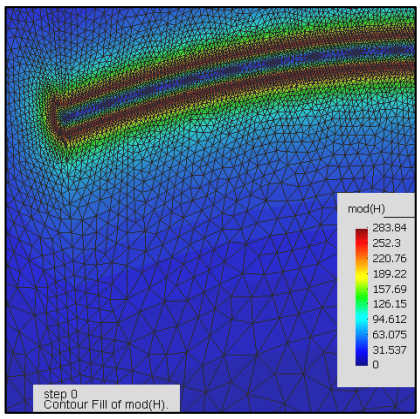


Fig. 4: Numerical results

Figures 3 and 4 show the mesh used and the simulation results respectively. Graph 1 shows the comparison between analytic and simulated results into the spire revolution axis (Label 1 fig. 3), which illustrate a good agreement between them.

A cone benchmark laboratory validation test [iii] was selected too. In fig. 5, the initial domain and coil geometry is shown (30º sector only). In this example, the Perfect Electric Conductor (PEC) condition was soposed to the sheet. The IGES and Bach format files make possible to build the model in an easy way.

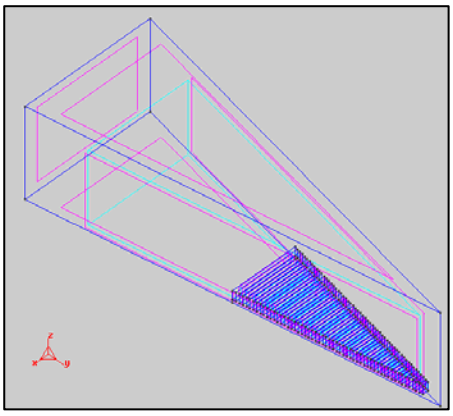
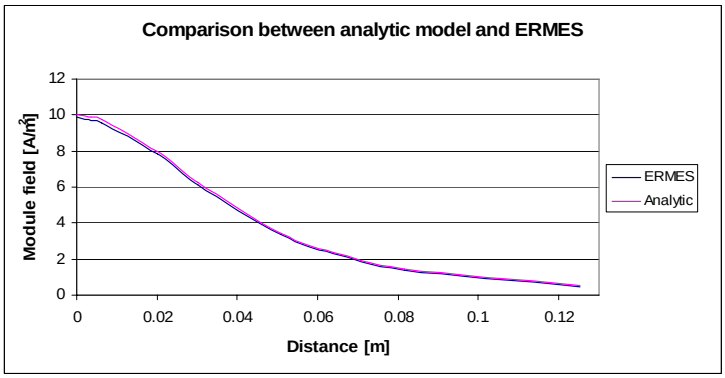


Fig. 5: Geometry of electromagnetic model



Graph. 1: Magnetic field vs. distance (respect the plane of the spiral) in numerical and analytic problem.

CIMNE has worked calculating the EM problem and the mechanical problem iterating manually. Thus, the need to do an automatic iterative simulation was analyced. The figures 6, 7 and 8 show the succession of the magnetic field in three different steps of forming simulation.

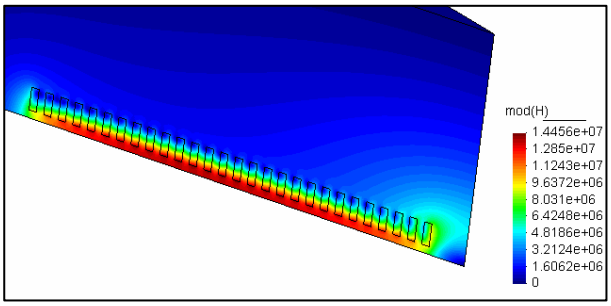


Fig. 6: Distribution of the magnetic field in the first iteration.

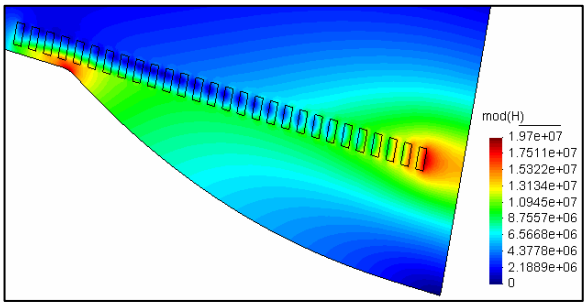


Fig. 7: Distribution of the magnetic field in the second iteration.

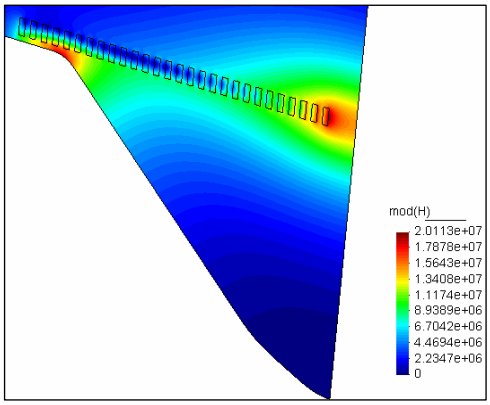


Fig. 8: Magnetic field in 3rd iteration

The field value decreases quickly as the distance to sheet increases. In the second and third step, the magnetic field is concentrated in the matrix accordance radius and in the magnetic coil axis.

Magnetic pressure (P) in PEC conditions is function of the magnetic field module (H) (equation (3)) and the vacuum magnetic permeability (μ_0):

$$P = \mu_0 \cdot \frac{|H|^2}{2} \qquad (4)$$

3 MECHANICAL PROBLEM

The mechanical code used is Stampack®. Its pre-postprocesors resources also are implemented in the GID platform. In order to modelling the problem, it's necessary also to import the initial and posterior sheet configurations from EM code. Due to the benchmark axisymmetry, the mechanical model is in 2D. Only 2D top line nodes of the sheet in deformed position in the time t_i is the input of the EM problem in time t_{i+1}. The experimental and the simulated results are shown in the figures 9 and 10.

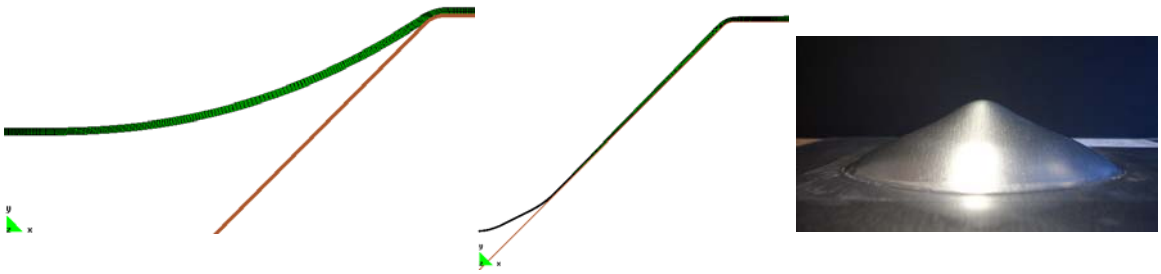


Fig. 9: Deformed in two different times and the experimental sheet formed (Courtesy of LABEIN-Tecnalia)

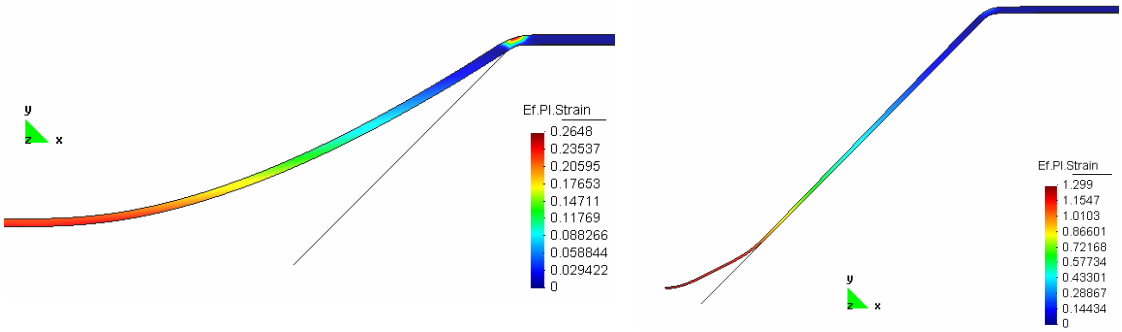


Fig. 10: Effective plastic strains in two different times of the process

4 CONCLUSIONS

- Pre and postprocessor GID platform is useful to work with simple or complex geometries in iterative manually coupled problems. The IGES, bach or dxf files, simplify the geometry transfer between EM and mechanical modules.
- The small gap between the sheet and the coil difficult the meshing. The use of tools like "unstructured size transitions" combined with "structured lines and surfaces" improves the control of non structured mesh generation in this zone. The automatic loops implementation at the moment is not possible.
- The standard visualisation tools of the results are used. The calculus of magnetic pressure is possible in user interface level. Specific visualization tools (calculus and visualization of volumetric forces) are under develop.
- To confirm the correct adjust of experimental results at lower and higher energy and frequency levels new benchmarks will be necessary.

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