Numerical Method to Solve Problems of Electromagnetic Forming of Thin Flat Plates in Matlab

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Abstract — This paper presents a simplified numerical method to solve problems of electromagnetic forming of thin circular flat plates using a flat spiral coil as actuator. The mathematical model is based on the Biot-Savart law, and the solution of magnetic induction integral equations is performed by numerical methods specifically with the use of Matlab commercial software. The calculation routine models the problem as a set of differential equations, which provides important information that serves as feedback for system design. Free bulging experiments were performed demonstrating a good relation with the mathematical model.

I. Introduction

An electromagnetic forming system is essentially a mutual induction system composed of an actuator coil and a conductive workpiece [1]. This process is based on a repulsive force generated by the opposing magnetic fields in adjacent conductors [2]. Several studies have started from this premise, but most involve situations for deformation of tubular parts by solenoid coils, while few studies have analyzed sheet metal forming by planar coils [1], [3].

The mechanical and electromagnetic phenomena of the process are strongly interrelated, and the deformation of the sheet metal affects the magnetic field and, consequently, the Lorentz forces developed. An approximate but more realizable approach is to treat the process as a loosely coupled problem, disregarding the influence of deformation of the workpiece in the evolution of the magnetic field, and then apply the forces generated by the electromagnetic field in the mechanical problem [2], [4].

This work will show a mathematical model of the electromagnetic forming system and numerical methods for solving a specific problem at the initial time before plastic deformation of workpiece. The method used approximates the flat spiral coil for circular and coaxial conductors, and the sheet metal is discretized in elementary segments of circular and coaxial conductors.

The main objective of this paper is to propose a simplified model of an electromagnetic forming system configured with a flat spiral coil as actuator, differing form others already presented [1], [3], [4]. At first, this model is based on the law of Biot Savart, and solves the obtained integrals by numerical methods implemented in an algorithm in software Matlab. This methodology serves as basis for the design of several components of the electromagnetic forming system. Also, another special feature from the proposed model is the possibility to change the process parameters and easily identify its influences as the employed theory in the construction of this algorithm is clearly identified in it.

II. Description of the Electrical and Electromagnetic Problem

A schematic model of the system analyzed is shown in Fig. 1. The calculations of the electromagnetic problem use a method based on discretization of the metal sheet in a number of circular elementary axisymmetric conductors.

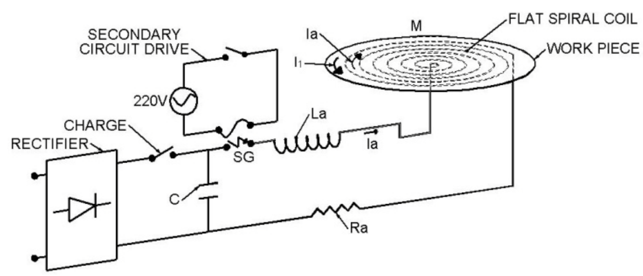

Fig. 1. Scheme of the electromagnetic forming system.

The transient electrical problem can be separated in a RLC primary circuit coupled with secondary RL circuit [5], [6], representing the set of ordinary differential equations in matrix form (1) and (2).

$$\frac{d}{dt}[\boldsymbol{I}] = [\boldsymbol{M}]^{-1}(-[\boldsymbol{R}][\boldsymbol{I}]) \quad (1)$$

$$I_a = C\frac{dV_c}{dt} \quad (2)$$

Where $\boldsymbol{I}$, $\boldsymbol{M}$, $\boldsymbol{R}$, I_a, C, V_c are the vector of the induced currents, matrix of the self and mutual inductances, matrix of the electrical resistances, current in actuator coil, capacitance, and electric potential in capacitor bank.

The magnetic field produced by the actuator coil can be computed by applying the Biot-Savart law. For points p(x,y,z) of the space it can be determined mathematically by equations (3), (4) and (5) in cylindrical coordinate system. This calculation is based on the work [7].

$$B_r = \frac{\mu_0 I_a z r}{4\pi} \times \int_0^{2\pi} \frac{\cos(\theta - \alpha)}{[x^2 + y^2 + z^2 + r^2 - 2r(x\cos\theta + y\sin\theta)]^{3/2}} d\theta \quad (3)$$

$$B_\alpha = \frac{\mu_0 I_a z r}{4\pi} \times \int_0^{2\pi} \frac{\sin(\theta - \alpha)}{[x^2 + y^2 + z^2 + r^2 - 2r(x\cos\theta + y\sin\theta)]^{3/2}} d\theta \quad (4)$$

$$B_z = \frac{\mu_0 I_a r}{4\pi} \times$$

$$\int_0^{2\pi} \frac{r - (y\sin\theta + x\cos\theta)}{[x^2 + y^2 + z^2 + r^2 - 2r(x\cos\theta + y\sin\theta)]^{3/2}} d\theta \tag{5}$$

$$\alpha = \tan^{-1}\left(\frac{B_y}{B_x}\right) = \tan^{-1}\left(\frac{y}{x}\right) \tag{6}$$

Where μ_0 is a magnetic constant and θ is angle between radius vector of the circular conductor and unit vector in x direction.

Figure 2 shows the ratio of magnetic field by ampere generated in the plane of the metal sheet for radial direction. Considering the symmetry of the problem, these values are the same in any radial direction.

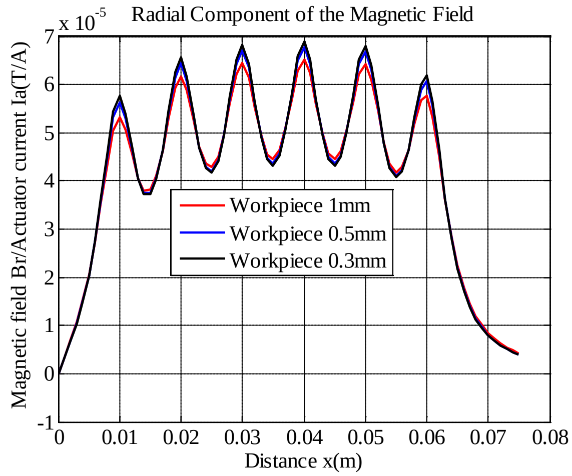

Fig. 2. Radial component of the magnetic field for different workpieces thickness.

III. The Electromagnetic Force

The metal sheet is discretized in coaxial circular elementary conductors (L1, L2...L12), where L1 and L12 are the outer diameter and inner diameter respectively. The electromagnetic force generated by each circular conductor can be calculated by (7).

$$Fe_n = B_r I_a I_n C_n \tag{7}$$

Where Fe_n, B_r, I_a, I_n, C_n are the electromagnetic force in the n^th circular conductor of the workpiece, the magnetic field in radial direction, the discharge current in actuator coil, the induced current in the n^th circular conductor of the workpiece, and length of the n^th circular conductor of the workpiece.

IV. Results and Discussions

Figure 3 shows the axial maximum transient electromagnetic force that occurs in 10^th (L10) elementary conductor of the workpiece. It can be seen that considerable forces are developed in this process and the highest difference phase between the discharge and induced currents causes a greater back (attraction) electromagnetic force when it's compared with electromagnetic force of repulsion (forming force).

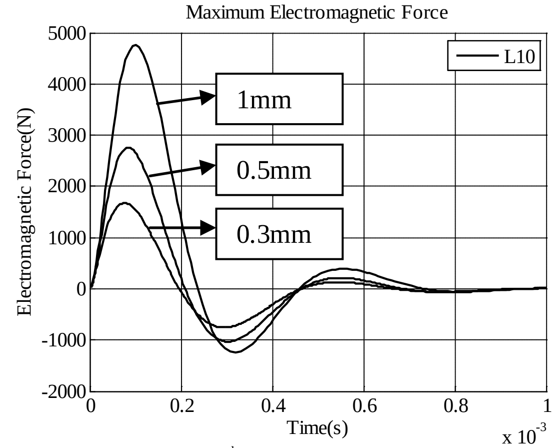

Fig. 3. EM force in the 10^th circular conductor of the workpiece.

Figure 4 shows experimental results for sheets of different thicknesses. It can be noted certain instability for the thinnest workpiece. One reason of this may be the action of the repulsive electromagnetic force (forming force) which is the lowest for the thinnest plate and even that a lower force is required to deform a thinner plate, there is the action of the back electromagnetic force (attraction force) that is relatively high compared to the repulsive force for the thinnest plates, as showed in Figure 3. This force attracts the plate soon after it is driven (pushed) by the forming force, causing the wrinkling.

Thickness 0.3mm Thickness 0.5mm Thickness 1mm

Fig. 4. Experimental results for different thicknesses.

V. References

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