I. INTRODUCTION

An electromagnetic forming (EMF) can be considered essentially like primary and secondary electrical circuits coupled by mutual inductances, composed of an actuator coil and a conductive workpiece. The EMF system geometry and parameters of pulse unit are very important to reach a high, optimum rise time, and adequate distribution of electromagnetic force to achieve a higher or adequate workpiece displacement. This study focuses on carrying out a parametric analysis by performing numerical simulations of free bulging of circular sheet metal by the EMF system using a spiral actuator coil with a single layer.

II. OBJECTIVES

1. Demonstrate the influence of EMF system parameters on the electromagnetic pressure, and consequently achieving higher or adequate workpiece displacement.
2. Use a numerical method to solve the fully coupled electric-magnetic problems applying an in-house script developed in the Matlab.
3. Solve the uncoupled mechanical problem using the ABAQUS Explicit Finite Element code.
4. Show comparative numerically predicted deflections versus experimental measurements to verify the calculation method;
5. Outlines doing principles for EMF systems of sheet metals.

III. BASIC METHODOLOGY OF ANALYSIS

The calculations of the electromagnetic process use a method based on discretization of the actuator coil into concentric (N) elements and the workpiece into multilayer concentric elements. The BLC primary circuit is fully coupled with several secondary RLs circuits and can be modeled using a set of ODEs applying Kirchhoff’s law. The inductances electric the magnetic phenomena.

\[ \frac{1}{i_0} \frac{d}{dt} \left[ L_{ij} F \right] = \left[ \begin{array}{c} \mathbf{E}_i \\ \mathbf{F}_j \end{array} \right] \]

This system of ODEs is solved by employing the explicit Runge–Kutta method inside Matlab 2015b (ODE45 function). The Biot-Savart’s law is applied to calculate the self and mutual inductances, and the electromagnetic force in the axial direction, respectively. Both \( B_0 \) and \( B_j \) use numerical methods to solve the equations.

The total electromagnetic force and consequent pressure along the c-axis is calculated using

\[ F = \sum_{n=1}^{N} F_n \]

The skin effect in the workpiece is an important electrical parameter to be evaluated, aiming the efficiency of the EMF process.

In the present numerical method, the skin effect is implicitly considered in the performance of the EMF system, it uses fully coupled electromagnetic and multilayer discretization.

IV. EXPERIMENTAL RESULTS

EXPERIMENTAL APPARATUS

EXPERIMENTAL RESULTS

The Peak of Electromagnetic Pressure Happens at the Same Moment of the Maximum Discharge Current

V. PARAMETRIC RESULTS

Maximum Discharge Current as Function of the Number of Coil Windings and Capacitance

VI. CONCLUSIONS

There exists an optimum time for the maximum electromagnetic pressure to happen, producing higher sheet displacements and this optimum time is related to the spiral coil geometry, and mainly with pulse unit parameters.

The greatest electromagnetic pressure is obtained for the highest number of coil windings along with the lowest capacitance, but the bulk EMF system configuration (geometry/machine) is observed for the capacitance value of 210µF.

The experimental results for \( N=6 \) and 60µF have good correlation with the calculated workpiece movements, demonstrating the effectiveness of this solution/method.

The EMF process is analyzed using a fully coupled electromagnetic, and uncoupled mechanical solution method, as a result the method can predict the reflected impedances from secondary circuits to a primary one.

Finally, this methodology can outline optimum and nonconflict parameters aiding in the design of the EMF equipment.