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Parametric Sensitivity Characteristics of Numerical Simulations on EMF Free Bulging of Circular Sheet Metal

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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 pressure, aming 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. This aproach can predict the reflected inductances from secondary(workpiece) circuits to a primary one(machine);
③ Solve the uncoupled mechanical problem using the ABAQUS/Explicit Finite Element Software;
④ Show comparative numerically predicted deflections versus experimental measurements to verify the calculation method;
⑤ Outline desing principles for EMF systems of sheet metals.

III. BASIC METHODOLOGY OF ANALYSIS

The calculations of the electromagnetic problem use a method based on discretization of the actuator spiral coil into concentric (N) elements and the workpiece into multilayered concentric elements. The RLC 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 couple the electric-magnetic phenomena.

$$\frac{d}{dt}[i]_{(1+mn)} = [M]^{-1}_{(1+mn)x(1+mn)}\left(-[R]_{(1+mn)x(1+mn)}[i]_{(1+mn)}\right)$$

$$i_a + C\frac{dv_c}{dt} = 0$$

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 magnetic field B_z and B_r, which are used to calculate the self and mutual inductances, and the electromagnetic force in the axial direction, respectively. Both B_z, and B_r use numerical methods to solve the equations.

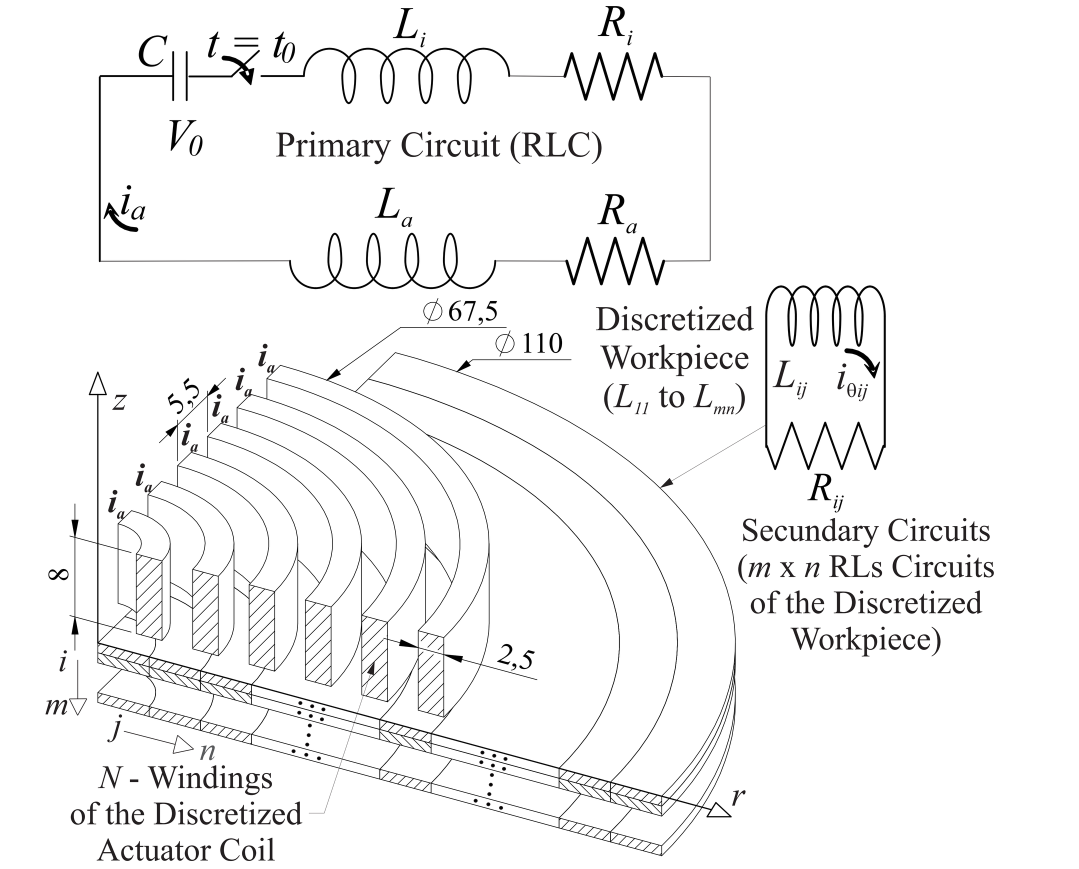
The total electromagnetic force and consequent pressure along of the r-axis is calculated using

$$f_{zj} = \sum_{i=1}^{m} B_{rij} i_{0ij} l_{ij} \qquad P_{zj} = \frac{f_{zj}}{\pi\left(r_{j+1}^2 - r_j^2\right)}$$

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, as it uses fully coupled electric-magnetic method, and multilayer discretization.

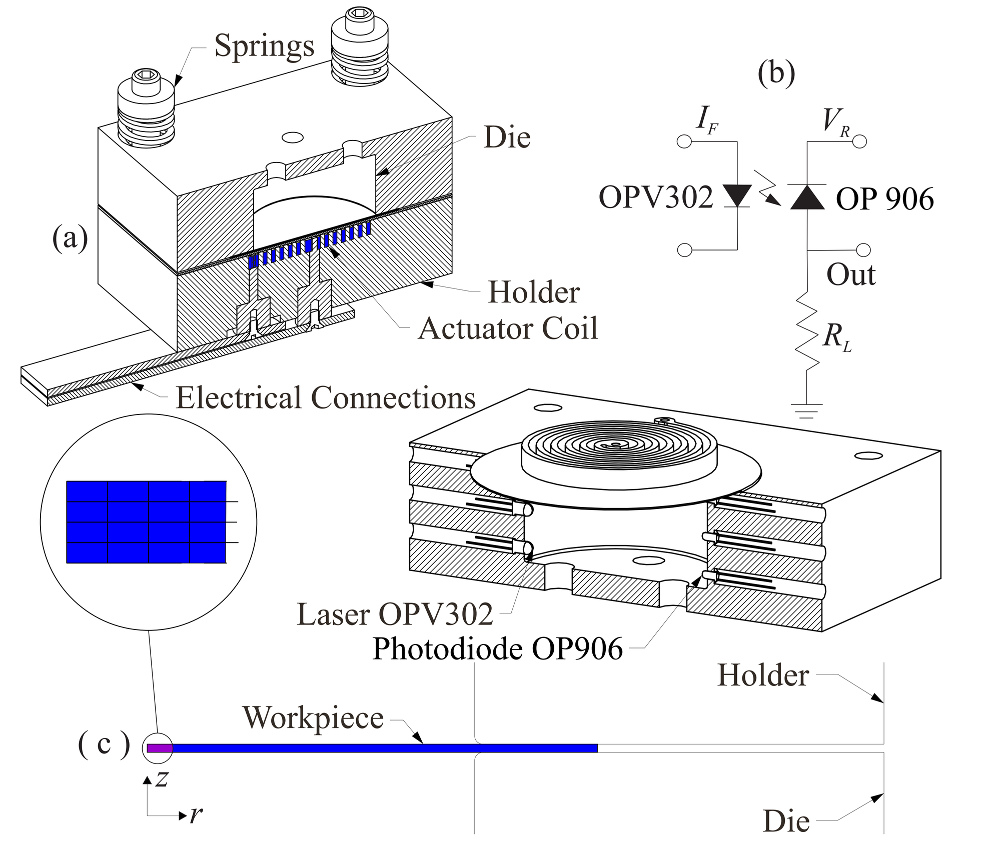
DISCRETIZATION OF EMF SYSTEM



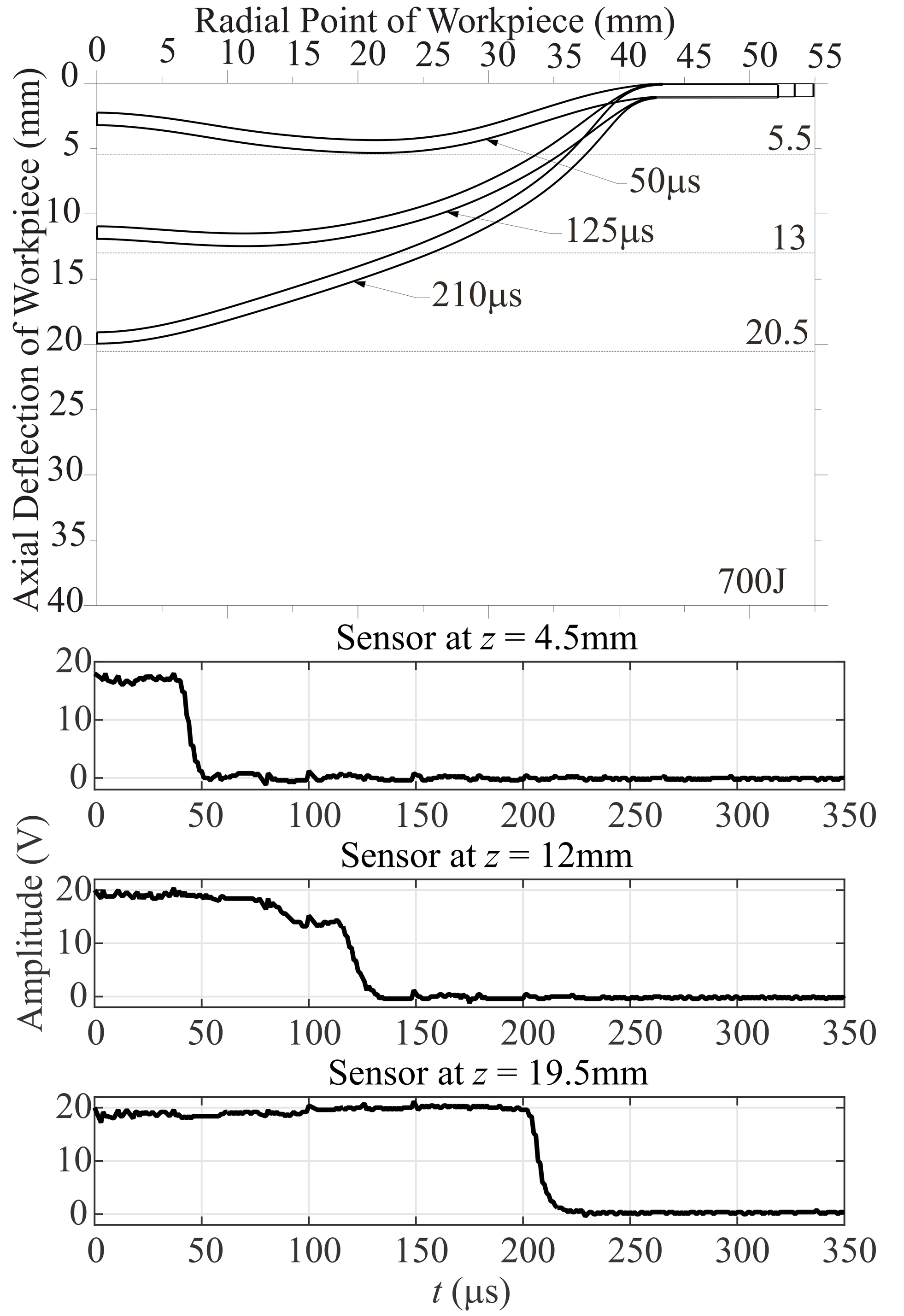
SYSTEM PARAMETERS USED FOR EXPERIMENTAL RESULTS

	Parameter	Value
Single-layer copper spiral coil	Number of windings (N)	6
	Outer diameter (D_0)	67.5mm
	Inner diameter (D_i)	7.5mm
	Pitch (P)	5.5mm
	Cross section (A_a)	20mm^2
EMF machine	Self-inductance (L_a)	0.9μH (calculated)
	Capacitance (C)	60μF
	Maximum energy (U)	1.5kJ
Workpiece	Material	AA1050 (annealed)
	Diameter	110 mm
	Thickness	1mm

EXPERIMENTAL APPARATUS

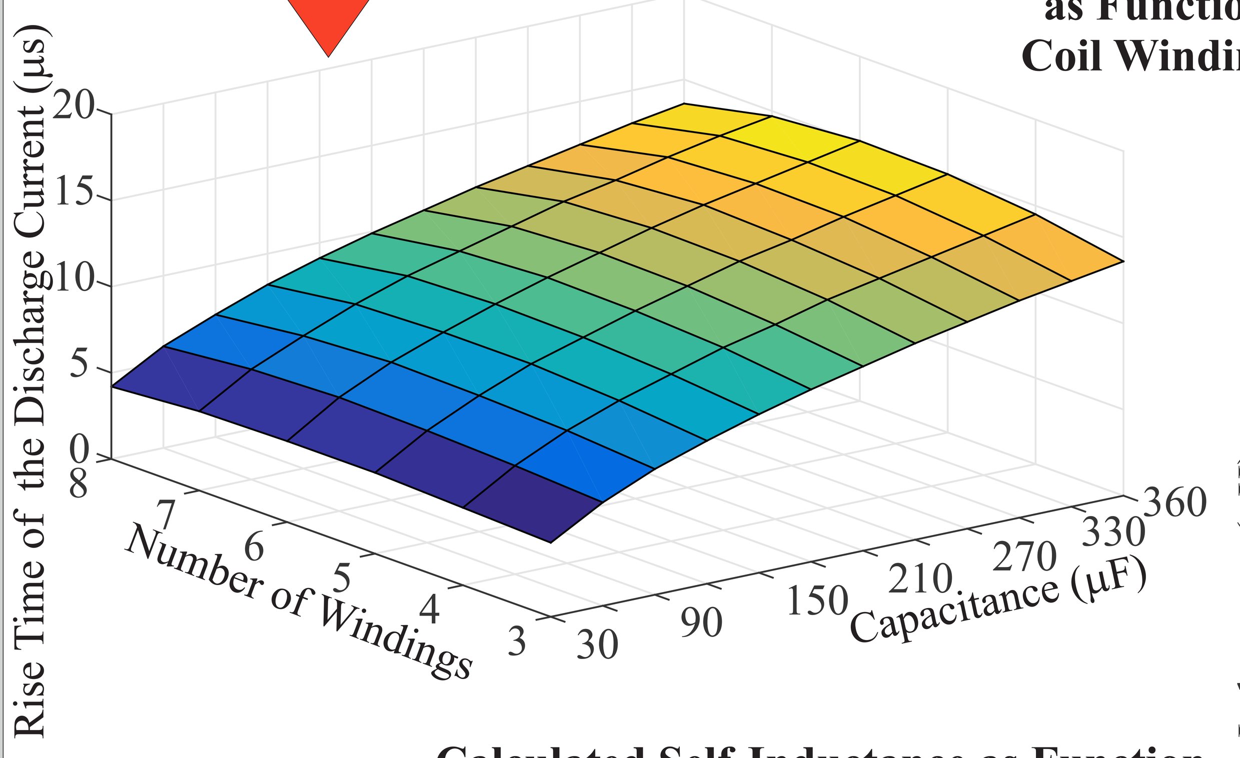


IV. EXPERIMENTAL RESULTS

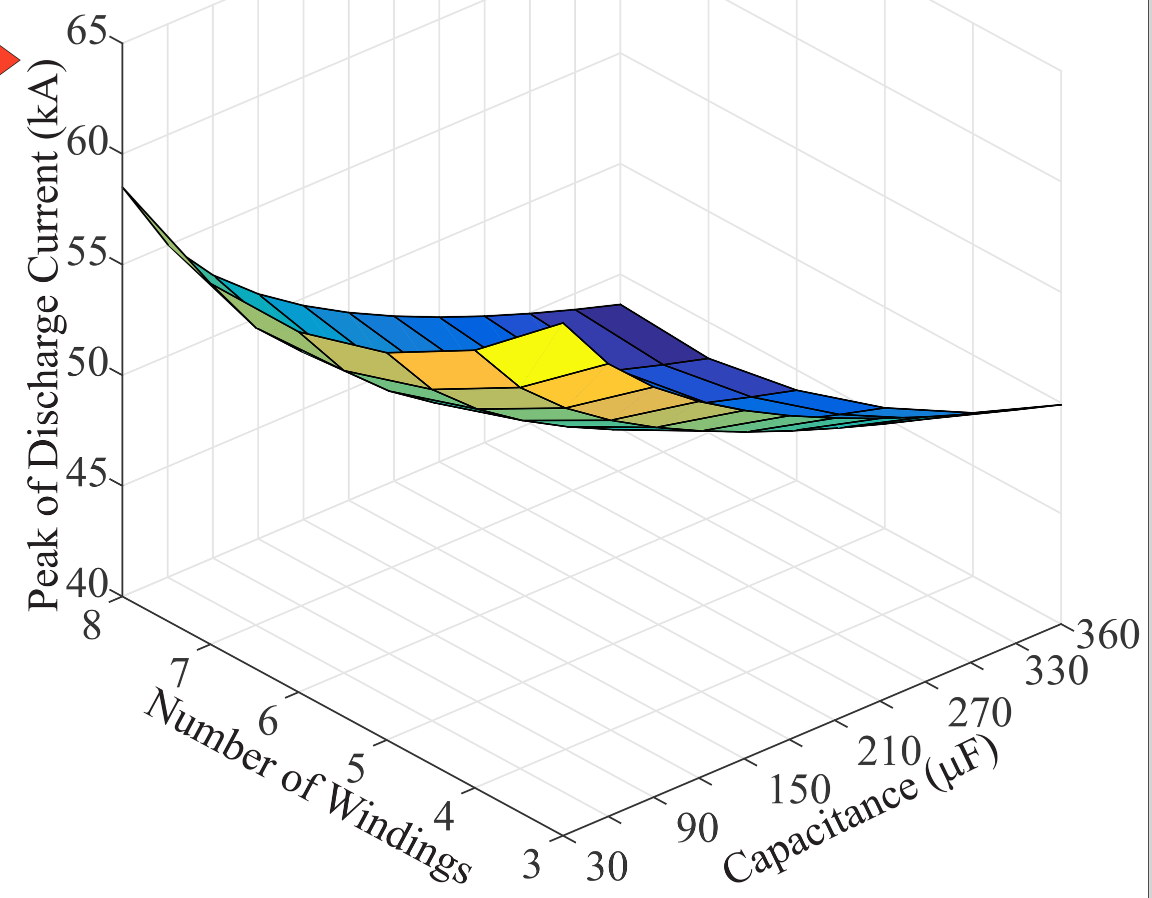


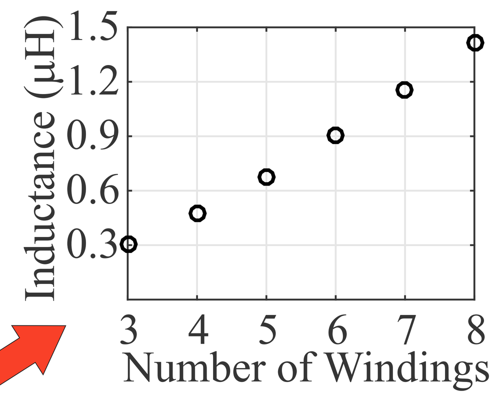
V. PARAMETRIC RESULTS

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



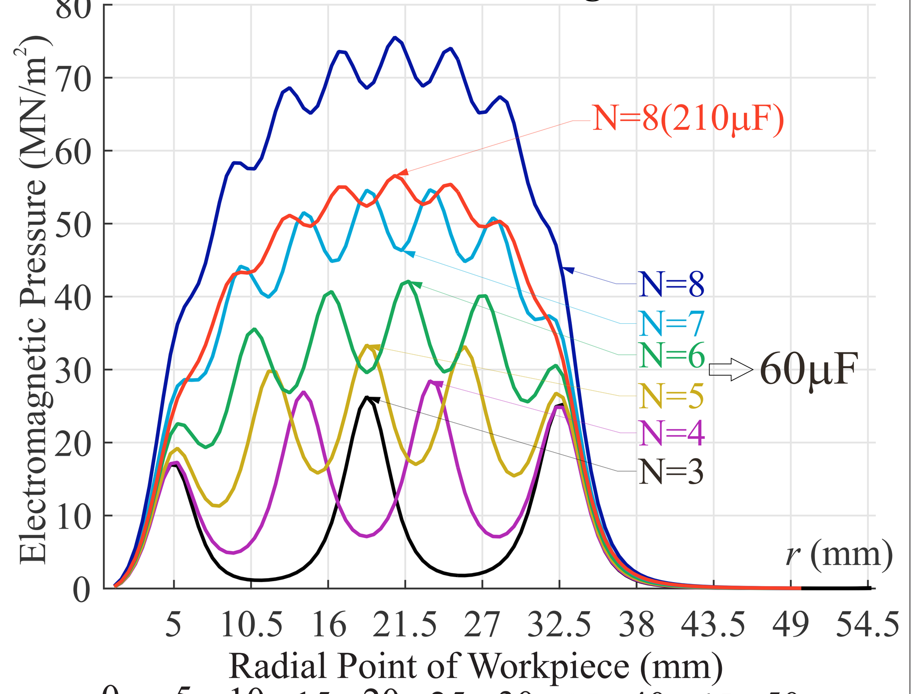
Maximum Discharge Current as Function of the Number of Coil Windings and Capacitance

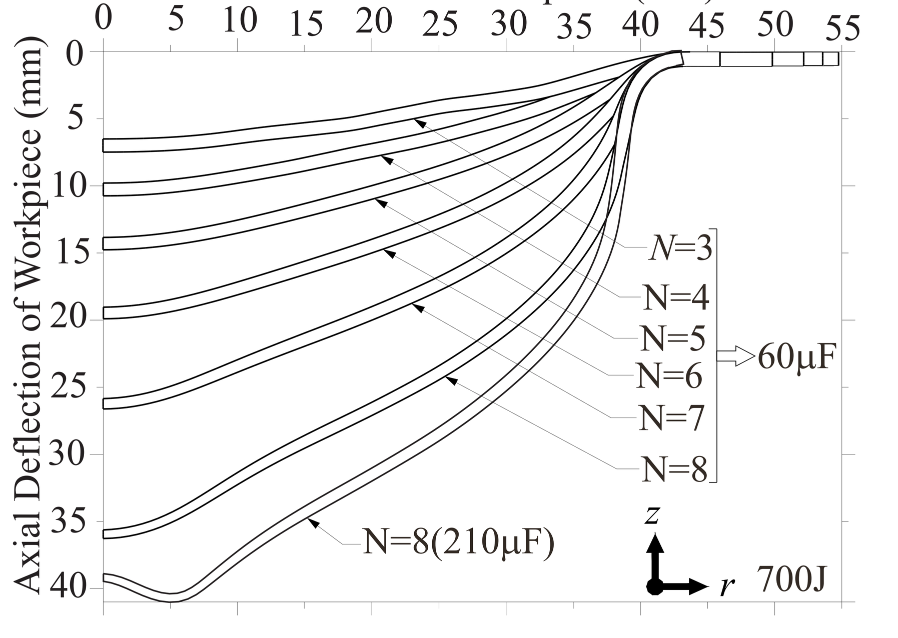




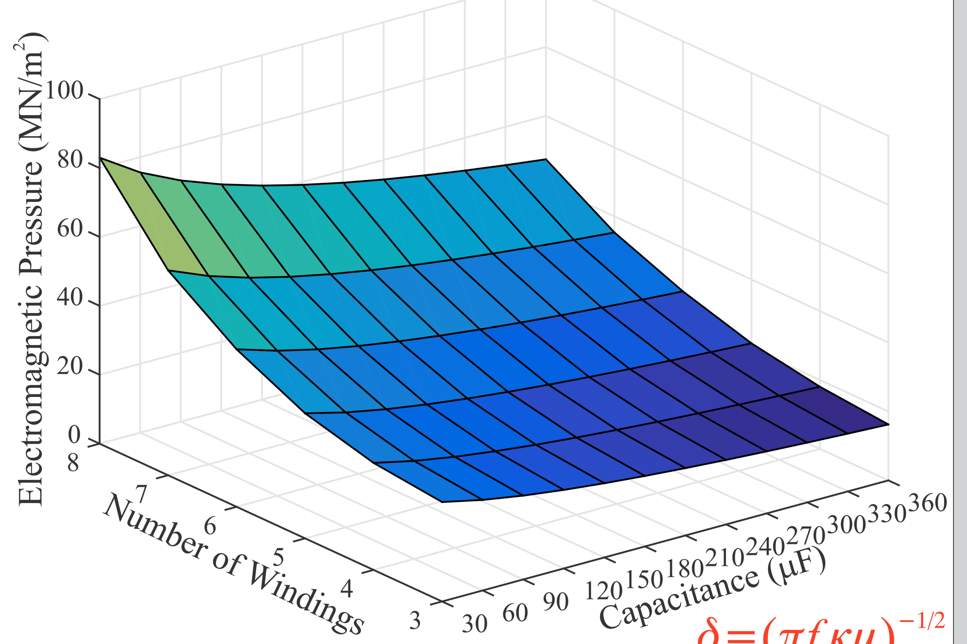
Calculated Self-Inductance as Function of the Number of Coil Windings

Distribution of Electromagnetic Pressure



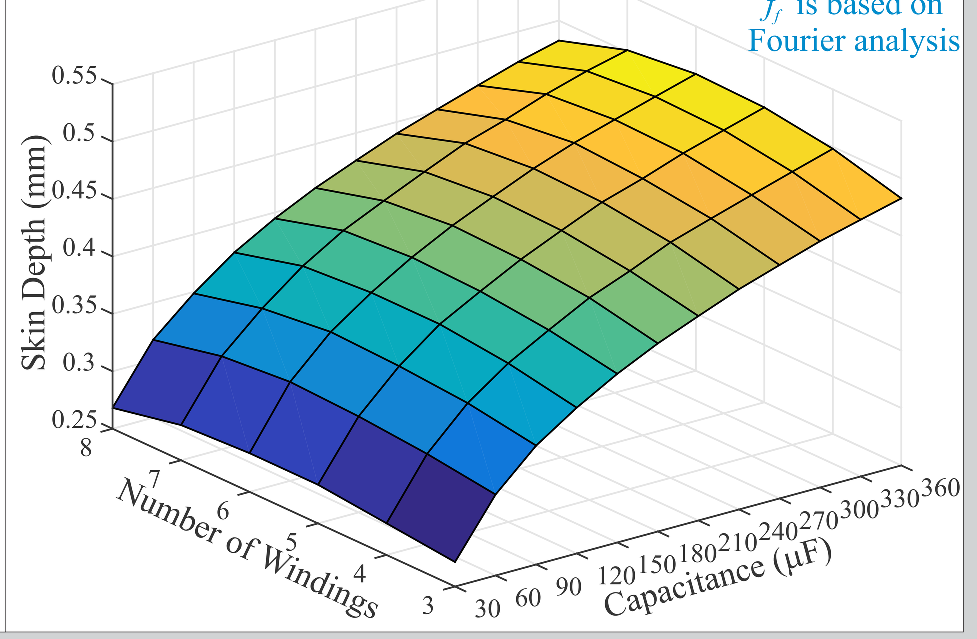


Maximum Electromagnetic Pressure



Skin Effect

$\delta = (\pi f_i \kappa \mu)^{-1/2}$
f_i is based on Fourier analysis



VI. CONCLUSIONS

① 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;

② The greatest electromagnetic pressure is obtained for the highest number of coil windings along with the lowest capacitance, but the best EMF system configuration (geometry/machine) is observed for the capacitance value of 210μF;

③ The experimental results for N=6 and 60μF have good correlation with the calculated workpiece movements, demonstrating the effectiveness of this solution methodology;

④ The EMF process is analyzed using a fully coupled electric-magnetic, and uncoupled mechanical solution method, as a result the method can predict the reflected impedances from secondary circuits to a primary one;

⑤ Finally, this methodology can outline optimum geometry and machine parameters aiding in the design of the EMF equipment.