

Analysis of electromagnetic field generated by a magnetic pulse joining machine

Khadija SOFI^{1,2}, Mohammed HAMZAOU¹, Hassan EL IDRIS²
Ahmed NAIT SIDI MOH¹, Abdelkrim HAMZAOU³

¹ LTI, EA 3899, University of Picardie Jules Verne, INSSET, Saint-Quentin, France

² LEEA-TI, Hassan II University of Casablanca, FSTM, Mohammedia, Morocco

³ LGECOS, Cadi Ayyad University, ENSA, Marrakesh, Morocco

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Email :
khadija.sofi@gmail.com
khadija.sofi@etud.u-picardie.fr



OUTLINE

- 1 Introduction
- 2 Analytical Model
- 3 Numerical Modelling
- 4 Current density distribution
- 5 Analytical and experimental results
- 6 Conclusion

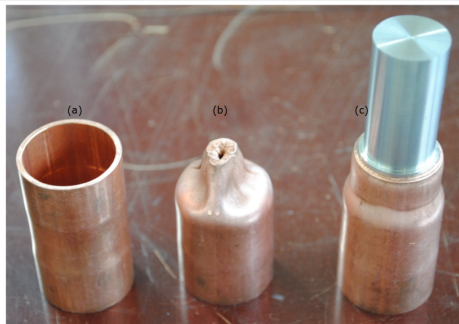
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Introduction

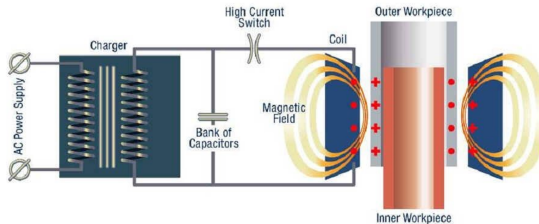
Deformation of metal pieces using electromagnetic field

- Magnetic pulse generator : represented by an RLC circuit
- Welding, forming and crimping of metal pieces.
- Thermal behaviour in the coil of the generator : 34 °C at a current peak of 150 kA.



MPW process

- Sudden discharge of power capacitors through a massive coil of copper alloy using Spark-gaps.
- Induced eddy current in the workpiece.
- A magnetic field is generated of micro-Teslas around the coil to a few Teslas at the center of the coil.
- Analytical design of the massive one turn coil using mutual inductance between two circular coils.
- Measuring the magnetic field around the coil using a flux loop.



Magnetic pulse welding process (Shribman, 2007)

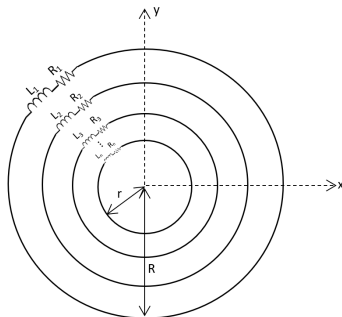
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Analytical Model

Mutual inductance of two circular coils

- A massive one turn circular coil is equivalent to a multi-turn one where each turn is represented by an inductance L_i connected to a resistance R_i
- The representation depends only on the geometry of the coil.

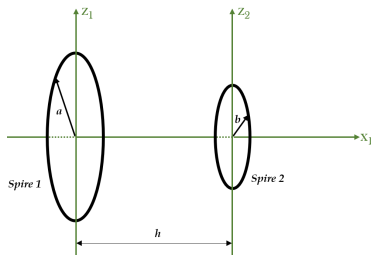


representation of a massive coil by a multi-turn coil

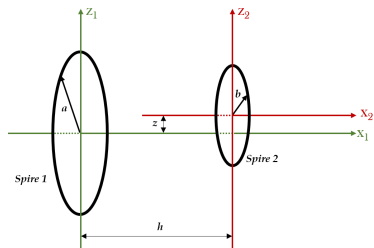
Analytical Model

Representation of the main coil and the flux loop

- Each loop of the coil is presented in figures below by spire 1.
- To obtain magnetic field, we used a flux loop, which is represented by spire 2.
- Experimentally, the magnetic field around is measured by connecting a flux loop, of radius 6cm and made of a copper wire, to an oscilloscope with a bandwidth of 1 GHz.



Coaxial configuration of coils



Non-coaxial configuration coils

Analytical Model

Mutual inductance

- Circular coaxial and parallel coils

$$M = \mu_0 k \sqrt{ab} \left[\left(\frac{2}{k^2} - 1 \right) K(k) - \frac{2}{k^2} E(k) \right]$$

- Non-coaxial parallel circular coils

$$M_{12} = \mu_0 \pi ab \int_0^\infty J_0(sy) J_1(sa) J_1(sb) e^{-s|h|} ds$$

Measuring magnetic field using flux loop

The voltage in the flux loop is :

$$V_2 = \omega M I_c$$

Magnetic field measured by the flux loop :

$$B = \frac{V_2}{\omega S}$$

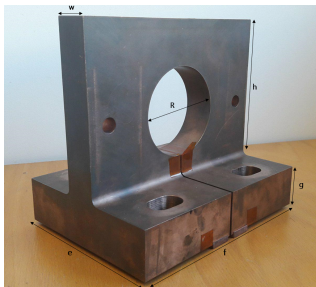
Where $S = \pi^2 b$: area of the spire and I_c is the current in the main coil

Outline

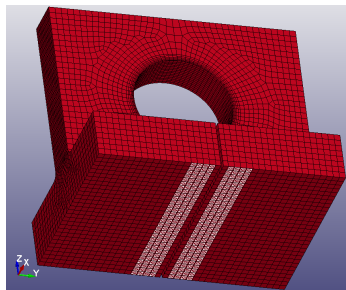
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3D Modelling

- 3D representation of the main coil



real coil



3D model using finit element method

Material	Mass density (kg/m^3)	Young's modulus (Pa)	Poisson's ratio
Siclanic	8.900e^3	1.30e^{11}	0.29

Material parameters

e (mm)	f (mm)	g (mm)	h (mm)	R (mm)	w (mm)
150	200	40	140	80	30

Coil dimensions

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Current density distribution

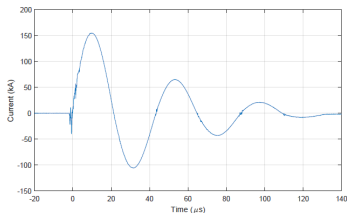
System of equations solved by Ls-Dyna

$$\nabla(\sigma \nabla \phi) = 0$$

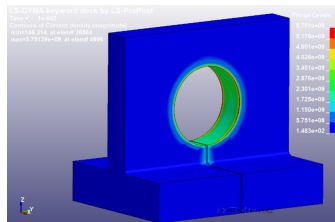
$$\sigma \frac{\partial \vec{A}}{\partial t} + \vec{\nabla} \times \left(\frac{1}{\mu_0} \vec{\nabla} \times \vec{A} \right) + \sigma \nabla \phi = \vec{J}_s$$

$$\vec{F} = \vec{j} \times \vec{B}$$

- Representation of the massive coil using finit element method
- The current is injected in bars of 20 mm width.

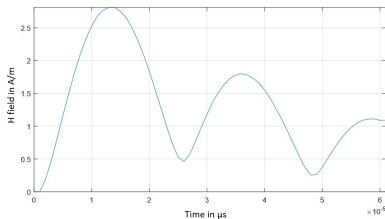


Current pulse in the coil

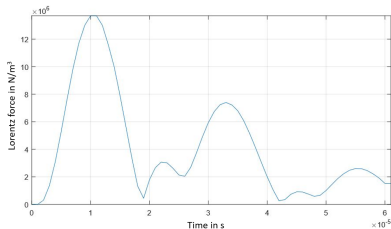


current distribution in the coil at $I_c = 150 \text{ kA}$

- Magnetic field H and Lorentz force density F



Magnetic field induced by the massive coil



Lorentz force magnitude

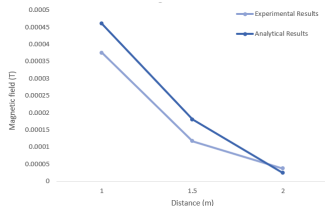
- The first big bumps in magnetic field and Lorentz force correspond to maximum and minimum current magnitude.
- When $I_c = 0$, J represents the generated eddy current in the coil.
- Presence of magnetization and hysteresis phenomena in the coil.

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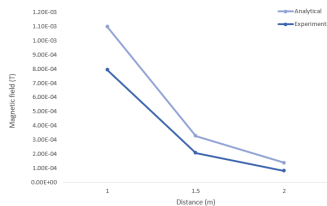
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Analytical and experimental results

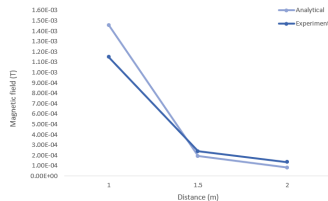
- The flux loop was placed respectively at 1m, 1.5m and 2m from the massive coil.
- The approximation between the analytical model and the massive coil in numerical simulation is due to the concentration of current density distribution in the center of coil.



Magnetic field at 2.5 kV



Magnetic field at 5.5 kV



Magnetic field at 8.5 kV

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Conclusion and perspectives

Conclusions

- Analytical modelling using a multi-turn coil can replace a massive one in terms of the produced magnetic field around it.
- Measuring magnetic field around the massive coil using a flux loop.
- using multi-turn coil designed analytically, we avoid heavy numerical simulations.
- Approximation between the analytical model and the massive coil in numerical simulation in term oof current density distribution

Perspectives

- Effect of the machine in an industrial environment on instrumentation equipment such as sensors
- Calculate analytically the Lorentz force applied on workpieces of different materials.

Thanks

QUESTIONS ?

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