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Proposal for a Test Bench for Electromagnetic Forming of Thin Metal Sheets

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1. Introduction and Motivation

In recent years, few studies have been presented for the design of EMF machines, whether for industrial or laboratorial applications [12,13].

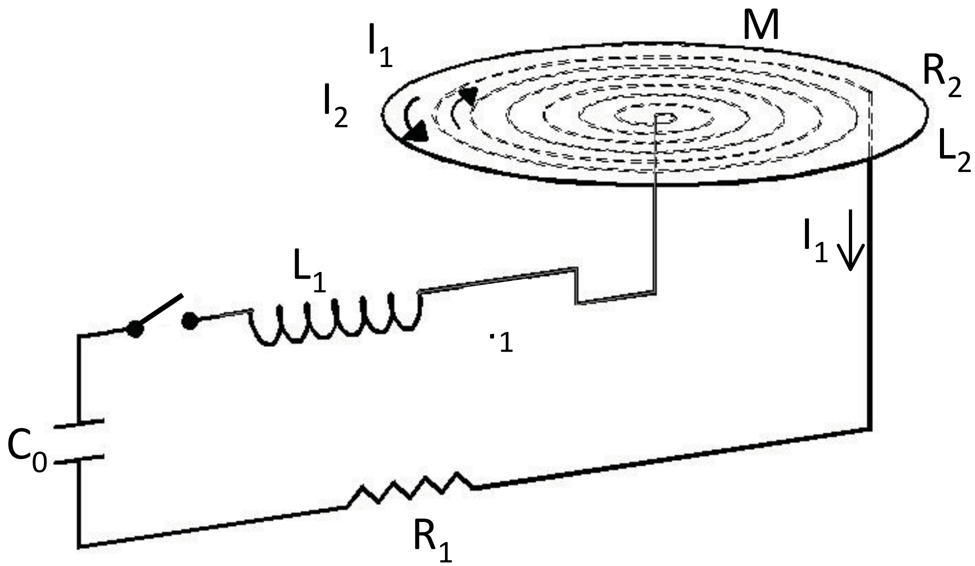
Peculiarities about Commercial EMF machines:

- Expensive equipment;
- Components with specific electrical properties are subjected to manufacture's availability
- Operates at high voltage (usually 10 kV).

In laboratorial experiments, the electrical data are very important, as it help the understanding and identification of relevant parameters to the process while also allowing the development of numerical models do design actuators and dies, as well process analysis.

2. EMF process

In a simplified way, an electromagnetic forming system consists of a capacitor bank connected to an actuator coil, which is very close to the metallic workpiece to be deformed:



Lenz Law

↓

Lorenz Law

↓

Workpiece deformation

An electromagnetic forming system is essentially a mutual induction system composed of an actuator coil and a workpiece. Any change in geometry of workpiece due to magnetic force alters the mutual inductance significantly, wich in turns changes the coil current and resulting magnetic force [14-19].

2. EMF process: analogy to electrical circuit

An electromagnetic forming system is a discharge circuit which consists of a primary RLC circuit coupled with a secondary RL circuit. Equations (1) and (2) describe the analogous electrical circuit of the system [19]:

$$(L_1)\frac{di_1}{dt} + \frac{d}{dt}(Mi_2) + (R_1)i_1 + \frac{1}{C_0}\int i_1 dt = 0 \qquad (1)$$

$$\frac{d}{dt}(L_2 i_2) + \frac{d}{dt}(Mi_1) + R_2 i_2 = 0 \qquad (2)$$

$$i_1 = 0, \quad (L_1)\frac{di_1}{dt} = V_0, \quad i_2 = 0 \qquad (3)$$

Where:

C_0 is the capacitor bank

L_1 and R_1 are respectively the total inductance and resistance of the primary circuit;

M is the mutual inductance between the coil and workpiece,

i_1 is the coil current,

i_2 is the equivalent induced current in the workpiece,

L_2 and R_2 are respectively the workpiece’s equivalent inductance and resistance

2. EMF process: Induced Magnetic Force and Magnetic Pressure Distribution

The induced magnetic force and pressure is given by equations (4) and (5) [9,11]:

$$\frac{F}{l} = \frac{\mu_0 I_1 I_2}{2\pi d} \quad (4) \qquad\qquad P = \frac{\mu_0 H^2}{2} \quad (5)$$

H is very dificult to determine because it depends:
-on time;
- on the space location;
- on the applied current and geometry of the actuator coil and the deforming workpiece.

Electromagnetic intensity distributions for idealized spiral coils have been analytically determined, but no general analytical solutions exist for sheet metal forming operations with flat coils [9,12].

3. Equipment

An EMF machine may be treated as an RLC circuit, equation 1, and is basically composed of a:

- high voltage DC power supply;
- capacitors;
- connecting lines;
- main discharge switch;
- actuator coil;
- dies;
- other devices to operational safety and control.

Most critical parts: main discharge switch and capacitors, which must be robust enough to withstand the high reverse voltage and current that may exceed 100 kA [13,20].

4. Design Solution for an EMF Test Bench

Design

- Technical aspects
  - *High current and voltage discharge.*
- Economic alternative to commercial solutions
  - *Cost, market availability and operational safety*
- Prerequisites
  - *DC power supply, monitoring (multitester) and data acquisition devices.*

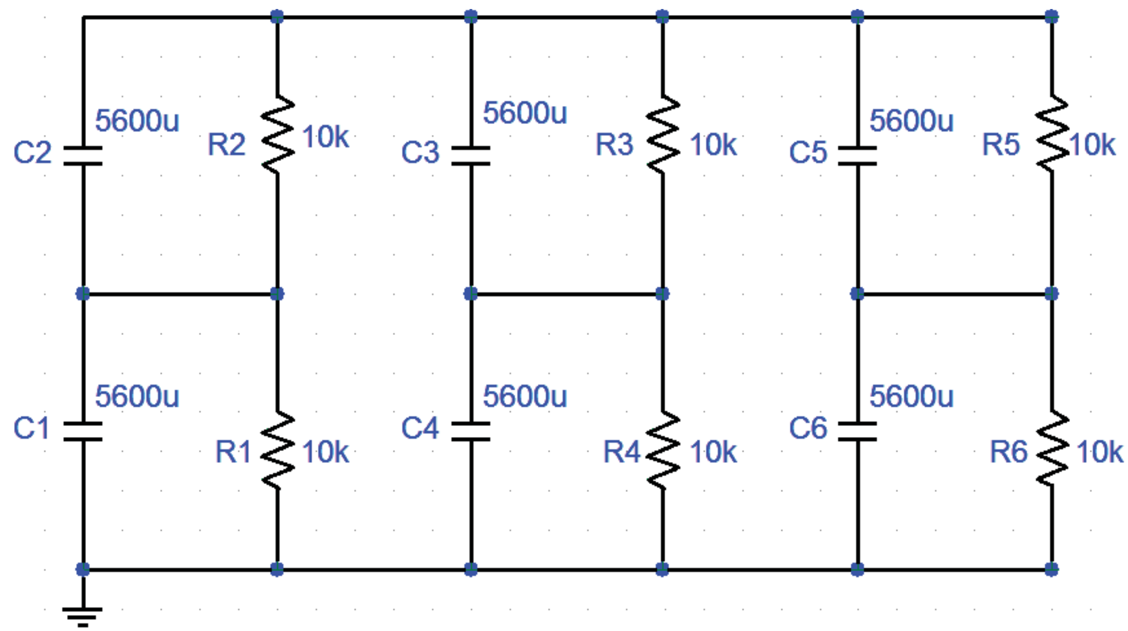
Warning: *people interested in following the assembly and operation of the presented machine need to use IPE and take special care when handling with high current and voltage.*

4. Design Solution for an EMF Test Bench

- Capacitors

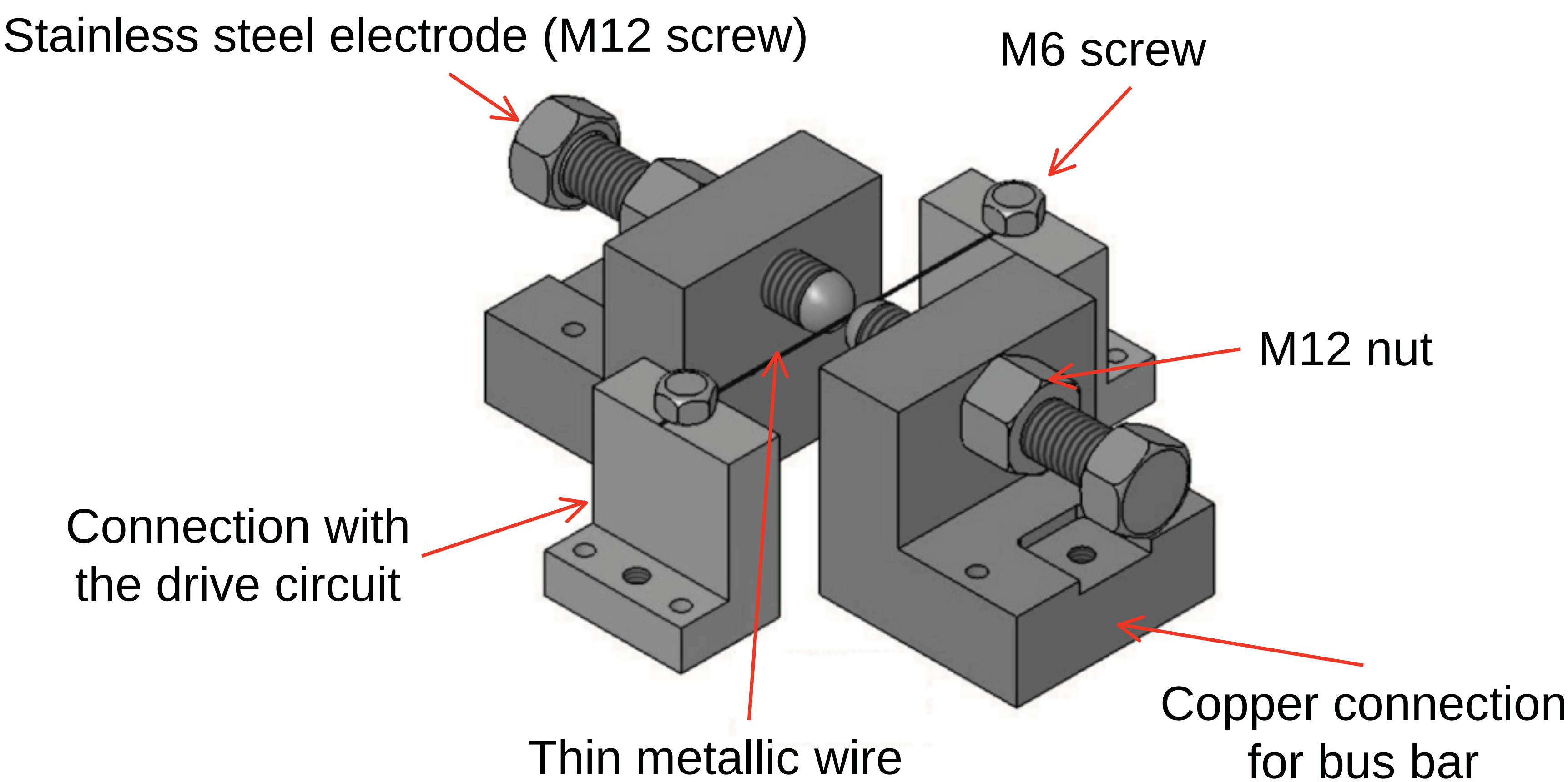
Commercial EMF machines exploit this relation by using capacitors of low capacitance and high voltage (thousands of Volts). For this project, EPCOS electrolytic pulse capacitors of 450 V and 5600 μF (±20%) were chose [21].

Capacitor bank



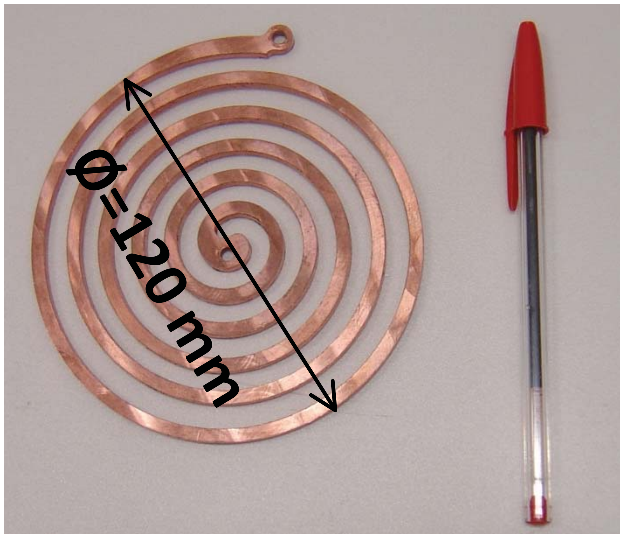
4. Design Solution for an EMF Test Bench

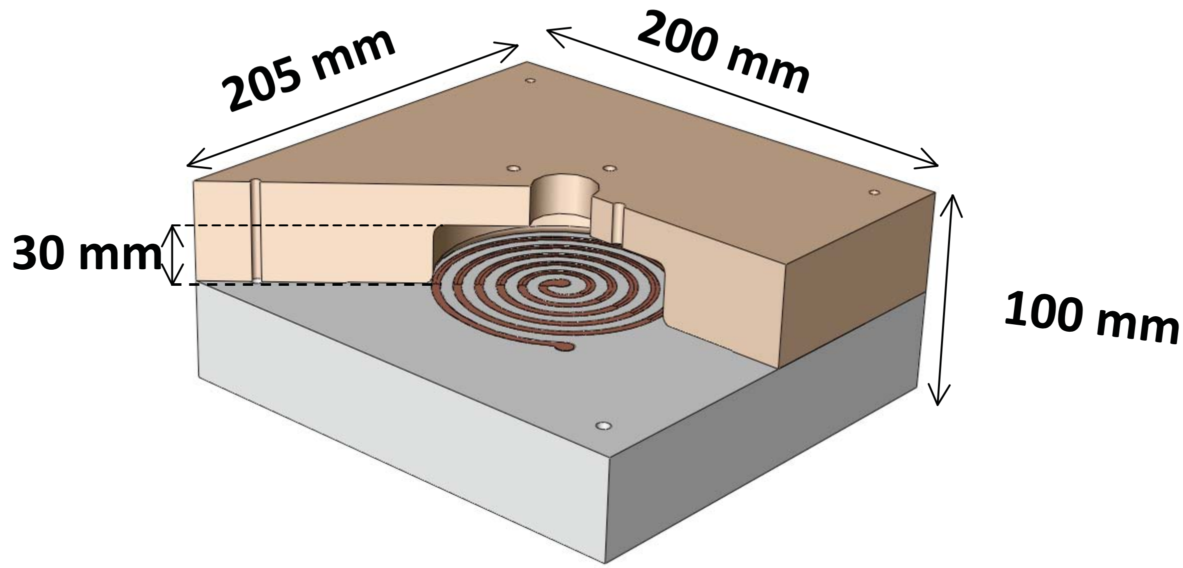
- Main discharge switch



4. Design Solution for an EMF Test Bench

➢Actuator coil and dies





Coil	Cross-section area Electrical resistivity Self inductance	16 mm^2 1.2396 mΩ (ohmmeter-D05 Cropico) 1.2 µH (LCR meter Minipa MX-1001)
Die mould	Material [22] Ultimate yield strength Hardness Dielectric strength	Tecaform AH (Polyoxymethylene) 60.7 MPa 86 HRM 19.7 kV/mm

- Connecting lines

Copper bars

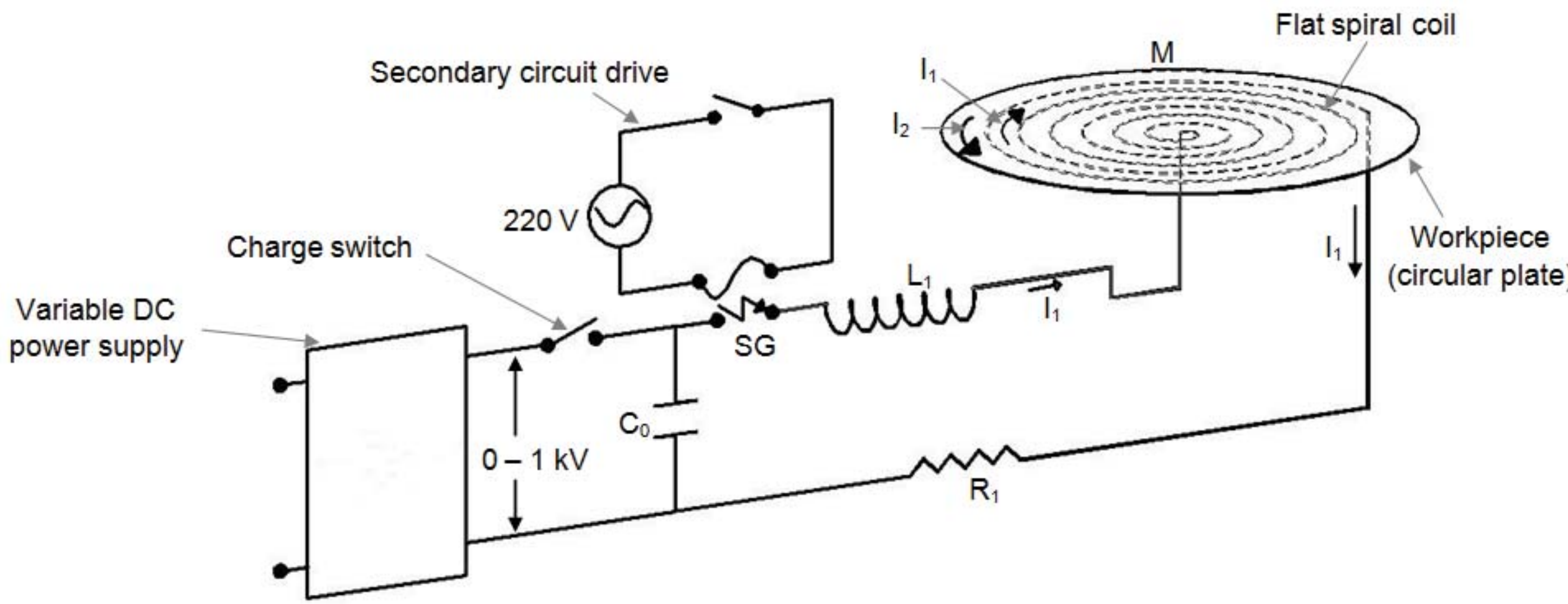
15.87 x 3.17 mm = 48.8 mm^2

Copper flexible connectors

2 x 18.3 mm^2 = 36.6 mm^2

http://www.acometal.com.br

- Electrical circuit configuration



4. Design Solution for an EMF Test Bench

- Bench test frame at LMEAE (Laboratory of Electrical Machines, Switch Drivers and Energy):

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4. Design Solution for an EMF Test Bench

Gpfai

- Procedures for operation of the test bench

i. checking if the system is energized and then discharge it if necessary;

ii. positioning the sheet on the die/closure and fixation of the dies with butterfly nuts;

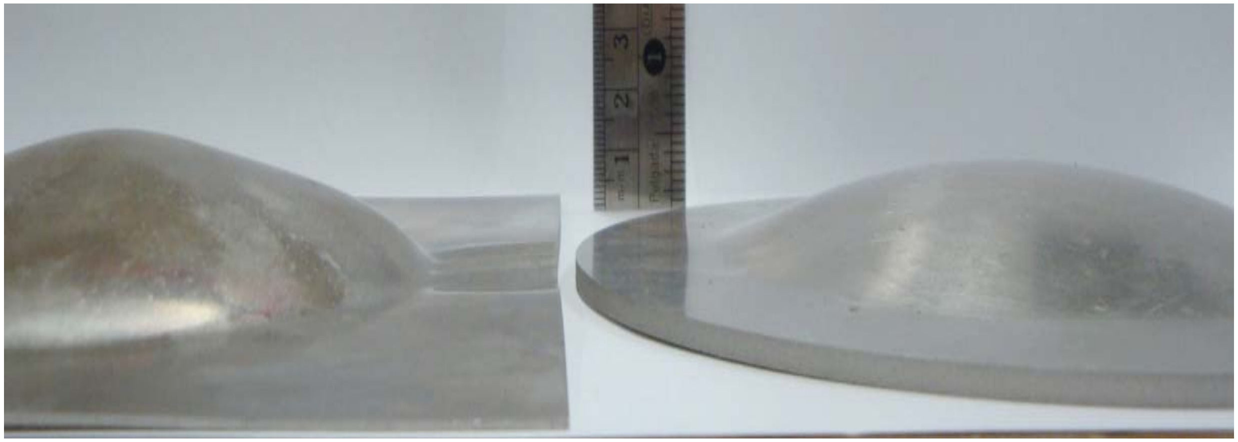
iii. Setup of the monitoring and data acquisition devices ;

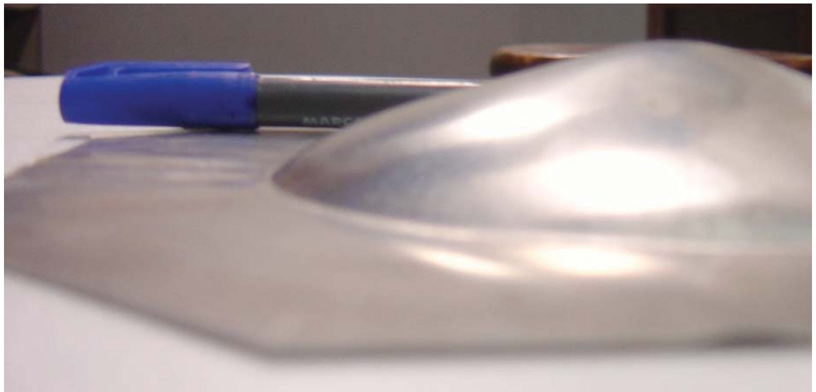
iv. start charging the capacitor bank with the desirable energy;

v. Once the charge is complete, the DC power supply must be disconnected from the capacitor bank and then the trigger circuit may be fired.

5. Results and discussion

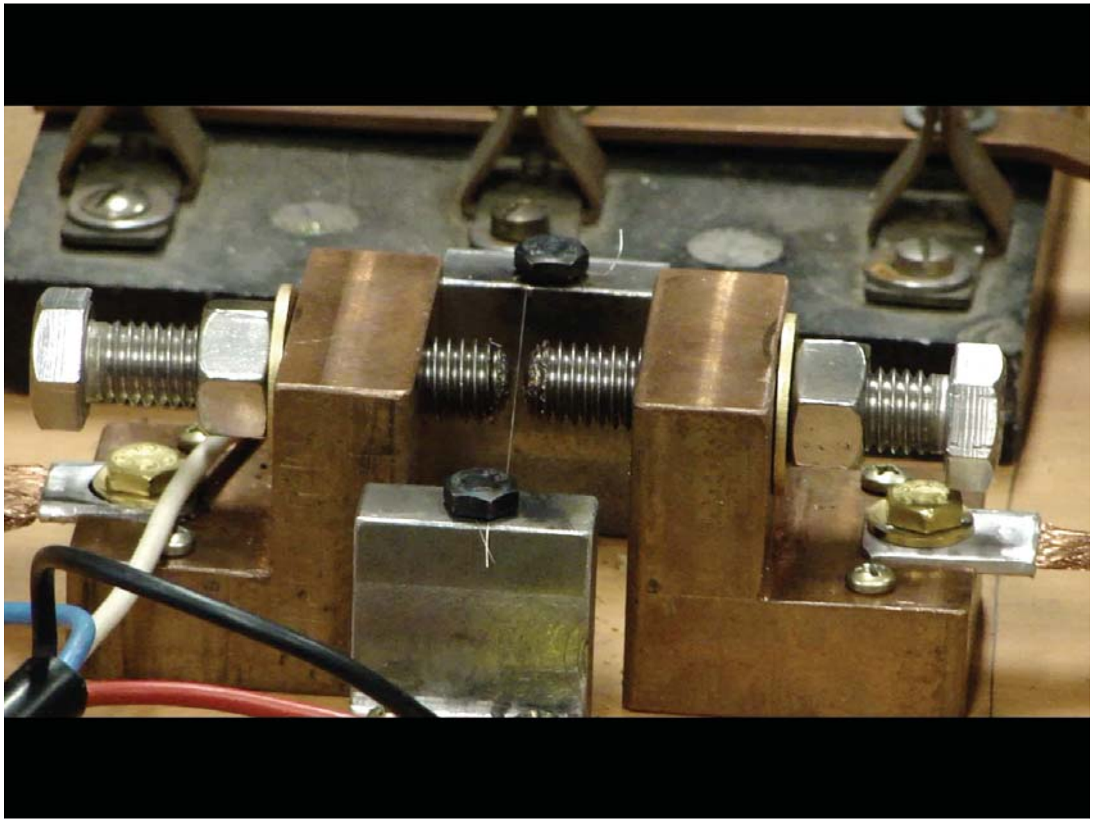
➢ Electromagnetic forming



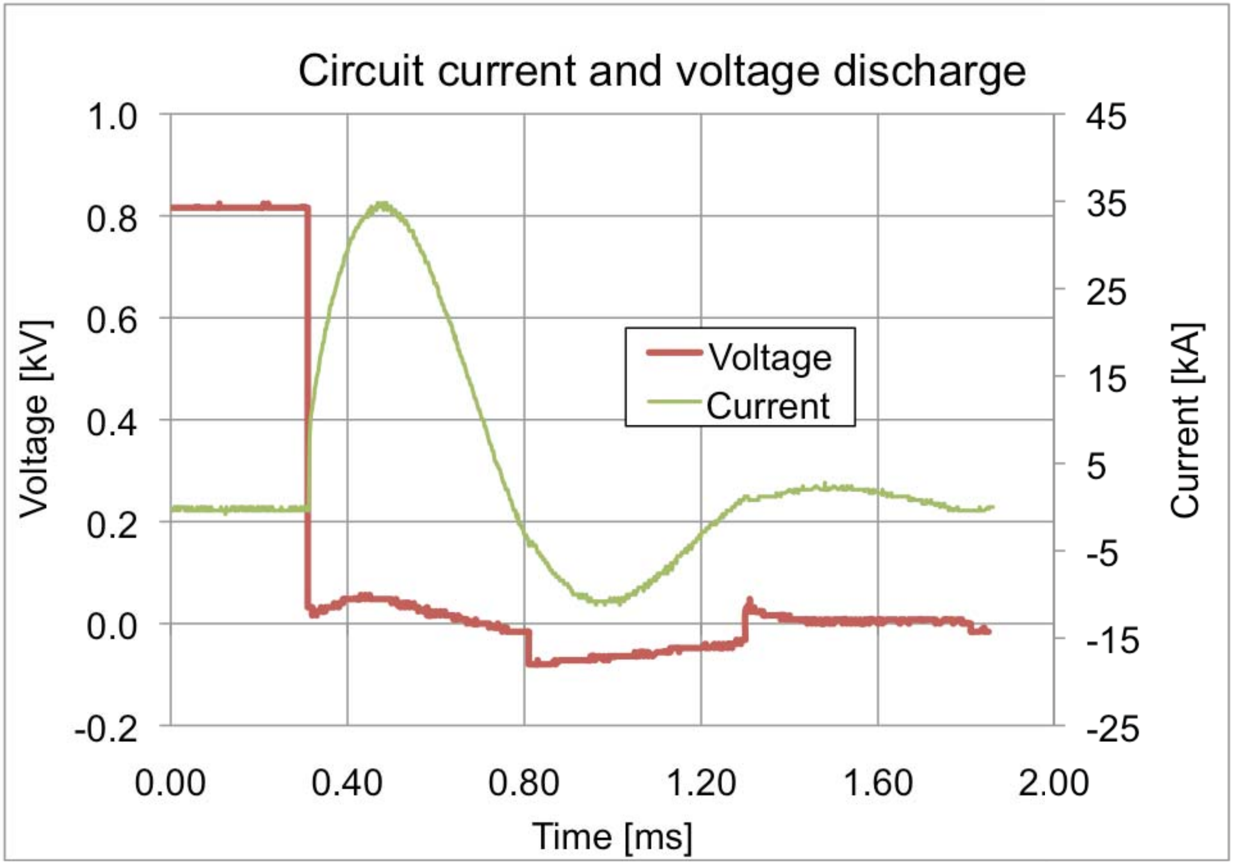


5. Results and discussion

➢ Spark-gap

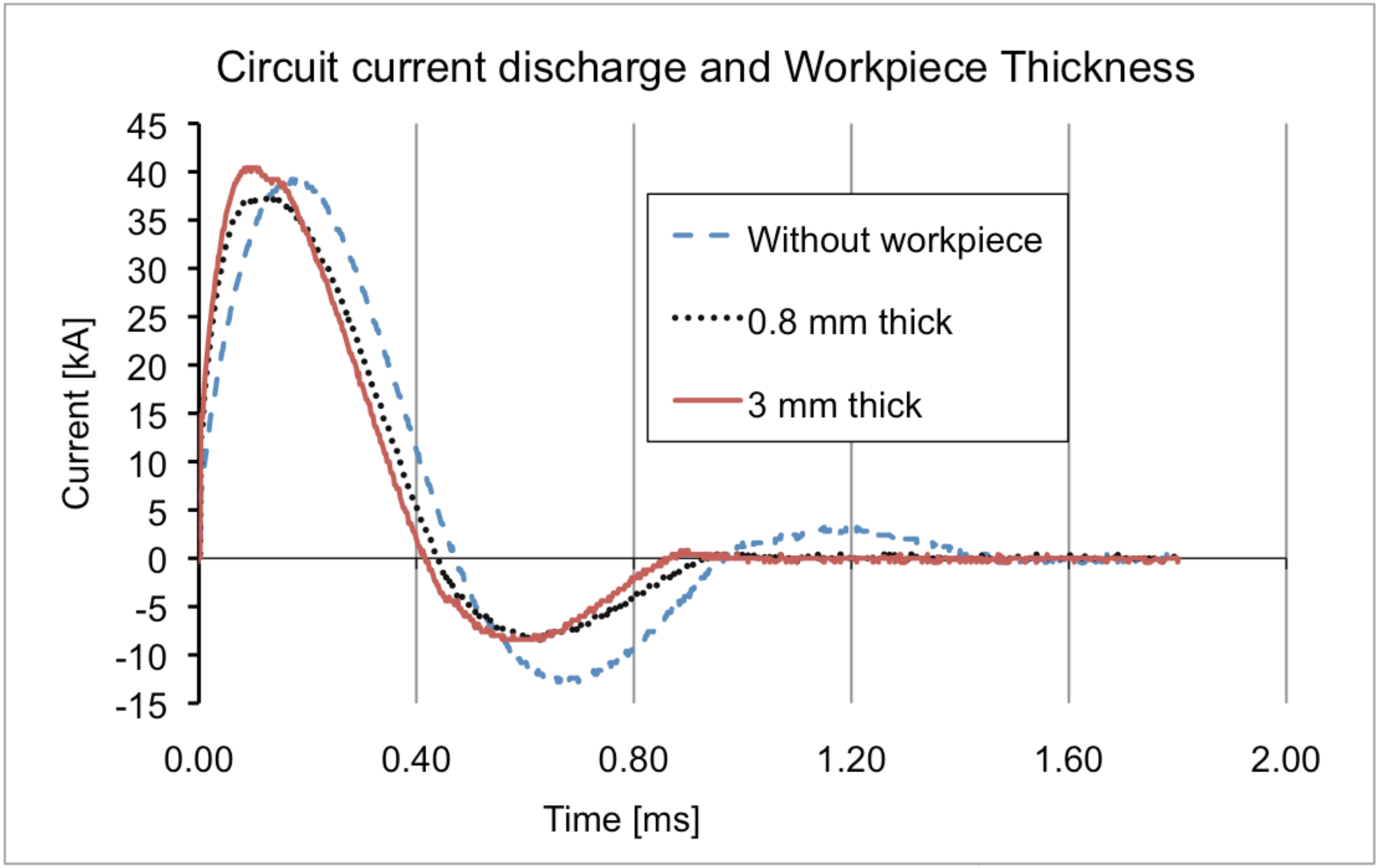


- Spark-gap: current and voltage discharge



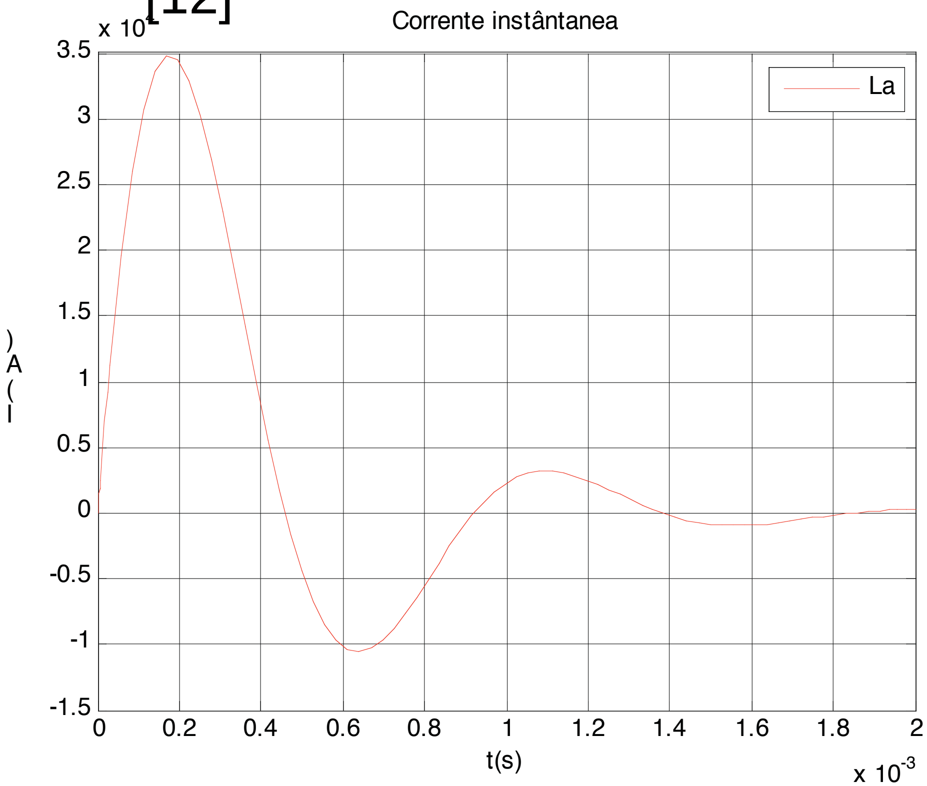
Parameters: 816V and without worpkpiece)

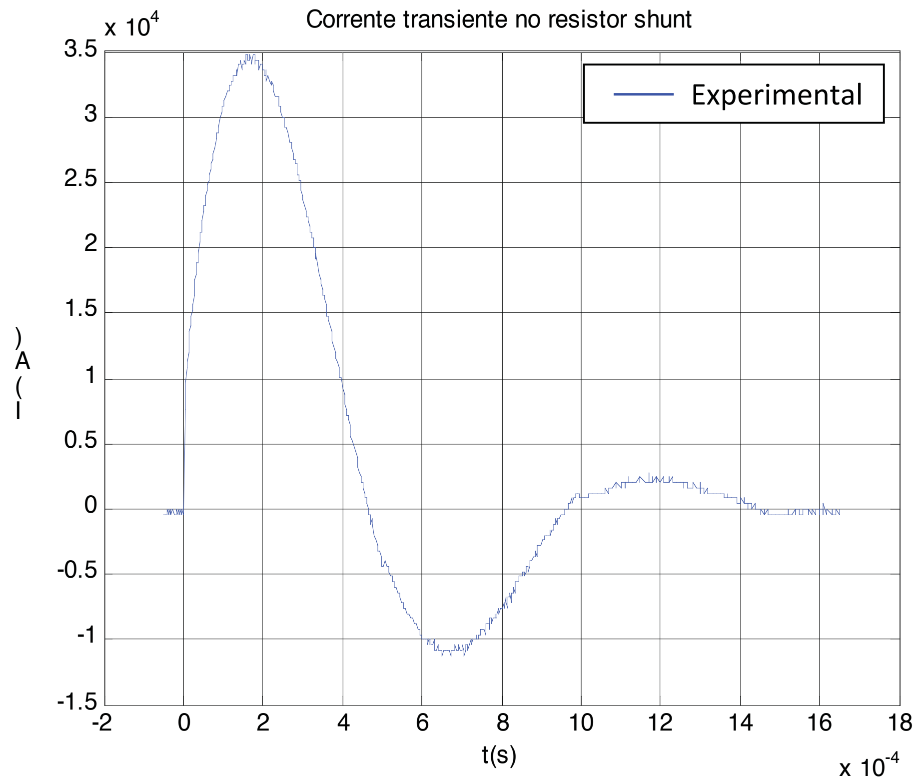
- Spark-gap: current and voltage discharge (experiments)



Parameters: 1 kV and without worpkpiece)

➢ Coil current discharge: numerical prediction *vs.* experimental results [12]





Parameters: 3.4 kJ @ 900 V and without worpkpiece and with input of electrical parameters from the machine (equivalent resistance and inductance)..

5. Results and discussion

- Wear

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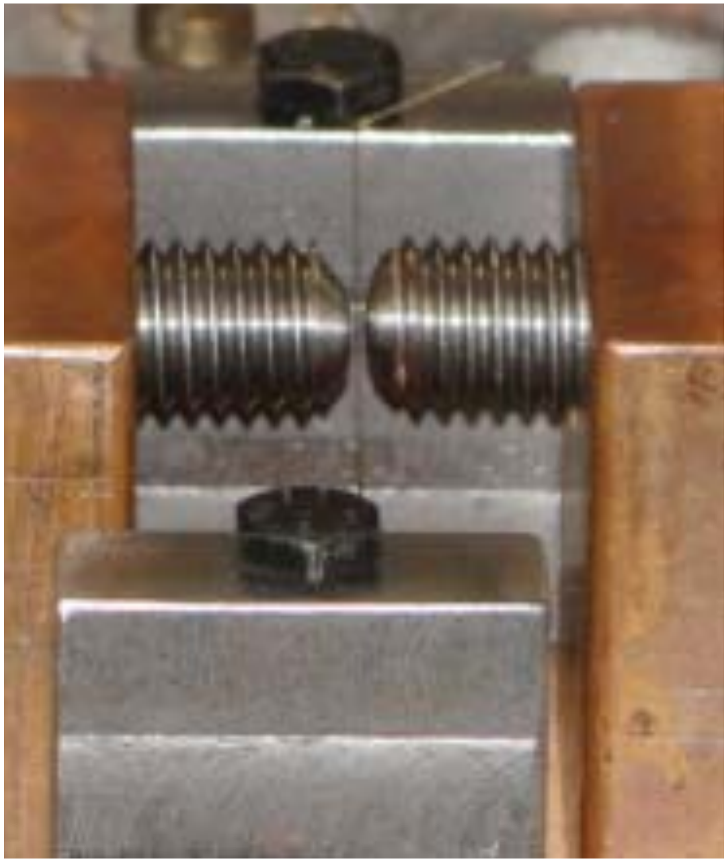
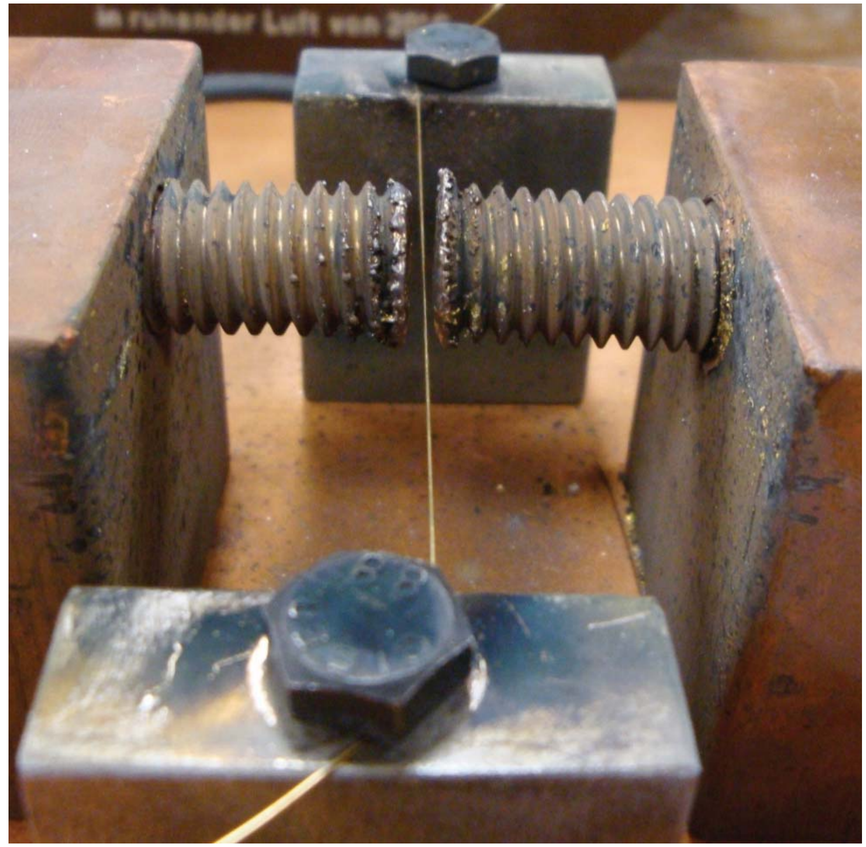
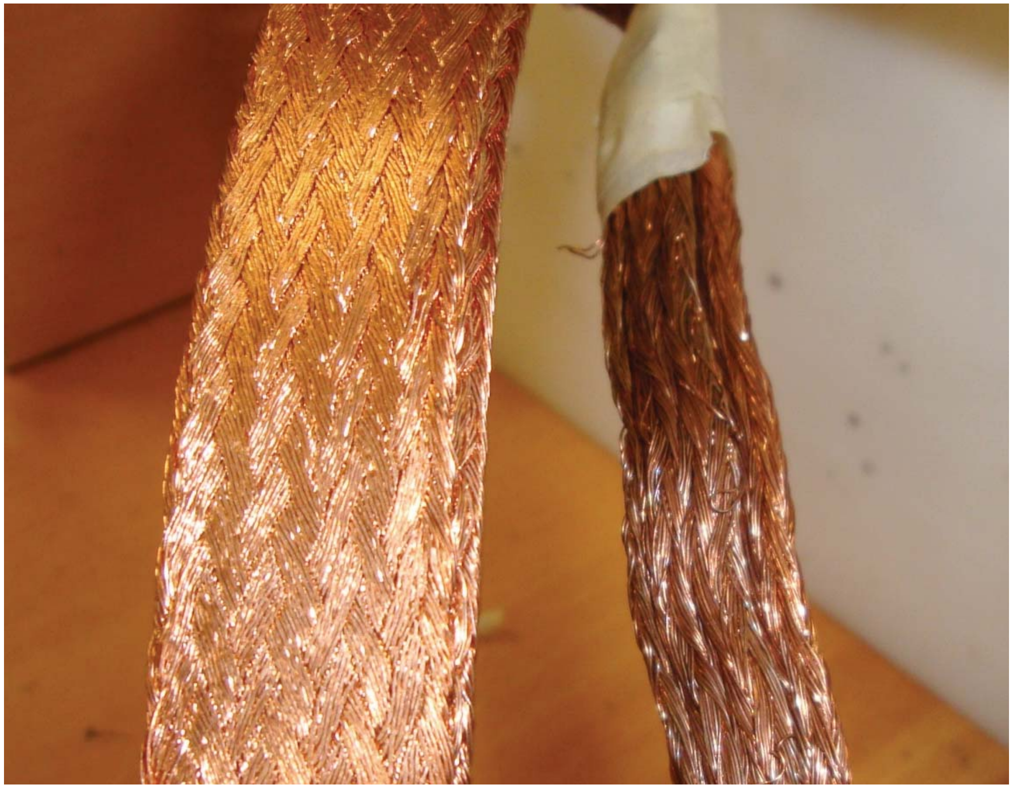
- Wear





5. Results and discussion

- Wear



6. Summary

✓ The paper presents a proposal of a test bench for electromagnetic forming of thin metal sheets for laboratorial experiments.

✓The presented design solutions are simple, functional and feasible.

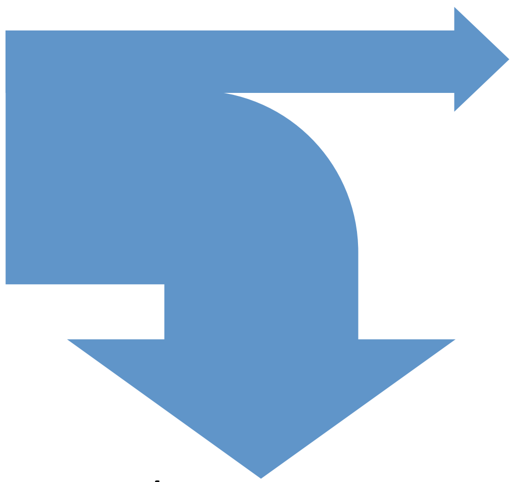
✓Aluminium sheet plates of up to 3 mm thick (Table 1) were successfully deformed by the presented EMF machine confirming that this concept serves as test bench and also as a reference for the construction of more powerful and robust machines and with higher degree of automation.

✓Acquired data for discharge current and voltage helped to identify process parameters and its influences, assisting in the development of other areas such as numerical modelling, die design and materials, and finally to the dissemination of this technique.

8. Future works

- EMF machine: more automation and safety.
- Determine the equivalent electrical parameters (R and L) to assist with the implementation of mechanical problem (plastic deformation) in new numerical models:

$$U = \frac{C \cdot V^2}{2}$$



Available energy for mechanical deformation

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Studies on numerical model for EMF analysis.

Dissipated energy:

- Equivalent resistance from primary circuit

$$U = \int R \cdot I^2 dt$$

→ Aid on efficiency coil design.

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