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MANUFACTURING METALLIC PARTS FROM COATED SHEET BY ELECTROMAGNETIC FORMING

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Abstract: *This paper aims to develop a technology for plastic deformation of metallic sheets covered by electromagnetic forming. The researches had also in view the following: forming behaviour of certain materials; the influence of the capacity and voltage of the capacitor bank on the flat sheets forming; the influence of the forming die material. Electromagnetic forming is the procedure that can be applied successfully to manufacture metallic parts from coated sheet (painted, galvanized etc.).*
Key words: *electromagnetic forming, parts, covered sheet*

1. INTRODUCTION

The ***electromagnetic forming (EMF)*** procedure is one of the most modern cold working technologies, with high power and speed, which was rapidly developed due to its multiple advantages such as (Bahmani et al., 2009; Karch & Roll, 2005; Risch et al., 2007): forming pressure is applied without physical contact, energy can be accurately controlled, the obtained parts have high dimensional precision, the tools and equipment are cheap and easy to maintain.

Deep-drawing is one of the forming operations, achievable by means of electromagnetic force. Figure 1 schematizes the deformation model (Takatsu et al., 1988) of a flat sheet (1) by means of a flat spiral coil (2).

An electromagnetic forming system is a discharge circuit which consists of a capacitor bank C, connecting lines with inductance L_c and resistance R_c, as well as a forming coil (L_1, R_1) coupled with the disk (L_2, R_2). Equations (1) and (2) describe the equivalent electrical circuit of the system:

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

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

where i_1 is the coil current, M is the mutual inductance between the coil and the disk and i_2 is the sum of eddy currents induced in the disk.

The initial conditions of equations (1) and (2) are:

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

where U is the initial voltage of the capacitor bank.

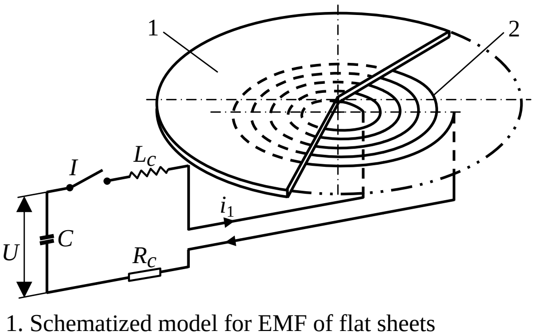

Fig. 1. Schematized model for EMF of flat sheets

In equation (1) the term Mi_2 is not a constant. It changes significantly with the deformation of the disk and, to a lasser degree, with the penetration of the field into the conductor.

The research described in this paper is limited to manufacturing metal parts by electromagnetic forming using energies between 0.4 and 4.9 kJ.

2. EXPERIMENTAL TOOLS AND EQUIPMENT

When designing the tools for EMF, besides general designing criteria (materials selection, dimensioning calculations and checking etc.), there are new requirements concerning the problem of modelling and directing the energy developed by the equipment. Based on general recommendations offered by literature two flat spiral coils for EMF were designed (Luca, 2000). These coils allow to obtained deep-drawn parts with diameters of 80 and 145 mm, respectively, as illustrated in Figure 2.

Experimental equipment comprises the following main elements (see Figure 3): 1- control board; 2- block of apparatuses; 3- high voltage generator; 4- rectifier unit; 5- starting switch; 6- capacitor bank; 7- forming tool.

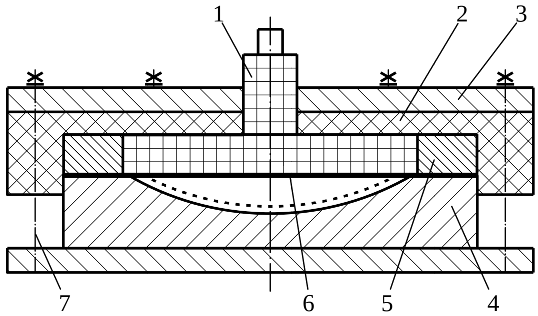

Fig. 2. Scheme of experimental tools: 1- flat spiral coil; 2- wooden casing; 3- fixing plates; 4- forming die; 5- ring; 6- workpiece; 7- tightening screws

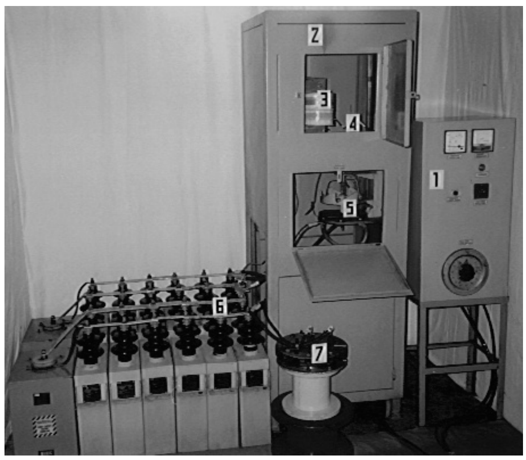

Fig. 3. Vue of experimental equipment

The main characteristics of the equipment are:

- maximum capacity of capacitor bank, 200 μF;
- discharge voltage of bank, 0...50 kV.

3. EXPERIMENTAL RESULTS

The first group of experiments aimed to establish the ability of different metallic materials to be electromagnetically deep-drawn, for which several tests were performed on steel, aluminium and zinc coated sheets.

The results obtained on steel parts have shown that these materials present a proper behaviour upon EMF. The depths of achieved parts were over 25 mm, the forming of rather thick sheets (1.2 mm) being accomplished, as well. As expected aluminium sheets are even very well formed by means of EMF, depths typically about 40 mm being obtained.

Zinc coated sheets were subjected to EMF as a consequence of the actual tendency in automotive industry to use deep-drawn parts obtained from sheets covered with a protective layer (painted, galvanized etc). In this case, though forming energies were large (4.9 kJ) resulted depths were smaller than 8 mm. This fact could be explained by the extremely high electric resistance of zinc (375 μΩ cm), much larger than recommended values for the materials subjected to plastic deformation by this procedure (30 μΩ cm). However the method might be valid for deep-drawing of metallic sheets coated with other metallic or plastic materials.

Next group of experiments aimed to emphasize the influence of discharge voltage and capacity of the capacitor bank on the depth of the free bulged disks.

The workpiece parameters were:

- sheet disk diameter: 110 mm;
- part diameter: 80 mm;
- thickness: 0.6 mm;
- material: deep-drawing steel sheet.

Forming coil has the following characteristics:

- number of windings: 10;
- coil diameter: 78 mm;
- material: electrotechnical copper.

Discharge voltage influence was first determined using a capacity of 200 μF and increasing values for discharge voltage, which led to the data listed in Table 1. Then plate disks were formed at constant voltage (6 kV) using different capacities of the capacitor bank (Table 2). With the data included in Tables 1 and 2, Figure 4 is obtained.

Regarding the influence of the forming die material on the depth of free bulged parts several experiments were performed on deep-drawing steel sheet. For this purpose, two types of tests were performed the only varying parameter being the material of the forming die. The above tests allowed obtaining the results included in Table 3.

Voltage, *U* [kV]	2	3	4	5	6
Energy, *E* [kJ]	0.4	0.9	1.6	2.5	3.6
Depth, *h* [mm]	1.8	6.1	10.3	14.4	19.3

Tab. 1. Values of forming depth as a function of discharge voltage of the capacitor bank

Capacity, *C* [μF]	100	125	150	175	200
Energy, *E* [kJ]	1.8	2.25	2.7	3.15	3.6
Depth, *h* [mm]	12.7	14.2	16.0	18.1	19.3

Tab. 2. Values of forming depth as a function of capacity of the capacitor bank

Energy, *E* [kJ]	0.9	1.6	2.5	3.6	4.9
h [mm], steel die	1.9	6.2	12.8	18.4	25.1
h [mm], textolite die	1.8	6.7	12.1	18.7	26.3

Tab. 3. Values of forming depth as a function of the material of the forming die

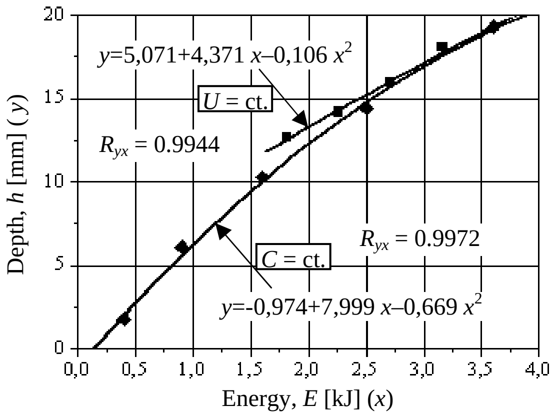

Fig. 4. Dependence of forming depth on the energy, for *U*=ct. and *C*=ct.

The workpiece parameters were:

- sheet disk diameter: 175 mm;
- part diameter: 145 mm;
- thickness: 0.7 mm;
- material: deep-drawing steel sheet.

Forming coil has the following characteristics:

- number of windings: 11;
- coil diameter: 170 mm;
- material: electrotechnical copper.

4. CONCLUSIONS

The results lead to the conclusion that both discharge voltage and electric capacity of the capacitor bank have a direct influence on the forming depth. For the same value of storage forming energy (0.9 kJ) a larger depth resulted by capacity variation (7.9 mm) as compared to discharge voltage variation (6.1 mm). This fact suggests that the change of bank capacity might have a more favorable influence on plate disks forming as compared to the change of the discharge voltage.

The material of forming die does not have a significant influence on EMF efficiency, the depths values being approximately equal in the case of the two experimental dies.

EMF is the procedure to be applied for deep-drawing of sheets coated with other metallic or nonmetallic materials.

Future research will aim to check the influence of parameters specific to the working tool (coil) such as: the distance between coil and workpiece; the number of windings of the flat coil; the shape of the winding section; the size of the winding section; the type of spiral.

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