*Environmental Engineering and Management Journal* January 2018, Vol.17, No. 1, 155-163
http://www.eemj.icpm.tuiasi.ro/; http://www.eemj.eu

*"Gheorghe Asachi" Technical University of Iasi, Romania*

# ENVIRONMENTALLY FRIENDLY PROCESSINGS BY ELECTROMAGNETIC FORMING IN AUTOMOTIVE INDUSTRY

**Dorin Luca**

*"Gheorghe Asachi" Technical University of Iasi, Faculty of Materials Science and Engineering, Department of Technologies and Equipments for Materials Processing, 51 Mangeron Street, 700050 Iasi, Romania*
*E-mail: dluca@tuiasi.ro; Phone + 40 232 278 680; Fax + 40 232 230 009*

**Abstract**

Reduction of environmental pollution in general, and emissions of greenhouse gases in particular, remain priorities for the sustainable development of human society. The strategies applied for designing industrial manufacturing processes were radically changed; nowadays the focus is mainly on the efficient use of energy sources. This means that at this moment there is a huge demand for innovative environmentally friendly technologies, for various industrial processing sectors. Electromagnetic forming is an advanced plastic deformation technology and is considered by many authors an environment friendly technology. Current studies suggest to apply electromagnetic forming in the automotive industry for the manufacture of low fuel consumption cars. It is expected that reducing the weight of cars (which supposes the manufacture of light car bodies by electromagnetic forming), will lead to a reduction in $CO_2$ emissions. Electric energy consumption for obtaining car parts by electromagnetic forming proposed in this paper is about 50 times lower than in case of conventional forming of these parts.

*Keywords:* electromagnetic forming, environmentally friendly technology, greenhouse gas emissions, transport sector

*Received: March, 2013; Revised final: May, 2014; Accepted: May, 2014; Published in final edited form: January 2018*

## 1. Introduction

It is known that in the last decades the problem of efficient exploitation of energy resources, especially fossil fuels, as well as decreasing the environmental impact by reducing emissions of greenhouse gases have become worldwide priorities to ensure a sustainable development of human society. Also, the European priorities are considering the economic growth based on technological progress and respect for the basic principles of sustainable development. The introduction of new manufacturing technologies and process optimization, targeted in the present paper as well, are research priorities that became a modern approach of the industry's problems from the perspective of sustainable development and eco-efficiency. Due to developments that occured worldwide in the last decades (industrial pollution, global warming and efforts for limiting emissions of greenhouse gases, etc.), energetic issue and efficient use of energy have become priorities for sustainable development of human society (Bostan, 2016; Carlsson et al., 2010; EEA, 2012; Kumar et al., 2008).

Integrated design of industrial processes and implementation of advanced manufacturing technology can ensure (Corabieru et al., 2015; Mellor et al., 2014; Torretta and Capodaglio, 2017; Wu et al., 2015):

- economic benefits, by significantly reducing energy consumption and therefore improving energy efficiency;
- environmental benefits, by reducing the environmental impact due to the decrease in emissions of greenhouse gases, mainly carbon dioxide per unit of product achieved.

An important part of scientific research in the environmental field is aimed to find solutions for cheaper energy sources and to reduce pollution and it is concentrated in several directions: use of biofuels, use of hydrogen as an energy source, reducing fossil fuel consumption. The use of biofuels continues to be a major preoccupation (Boutin et al., 2007; Lakó et al., 2008; Mateescu et al., 2008; Mofijur et al., 2016), due to the increase of global energy demand and the need to reduce emissions of greenhouse gases (Gavrilescu M., 2008) obtained by burning fossil fuels. An important source of biofuels is represented by the biomass from the cellulose and paper industry (Fortuna et al., 2012; Gavrilescu D., 2008a), which is at the same time a major producer of $CO_2$ (Gavrilescu D., 2008b).

Hydrogen is considered *"an energy vector for the future"* (Păsculete et al., 2007), due to its many advantages: it can be converted into various forms of energy; it is an unlimited source of energy because it is obtained from water and it is transformed into water after use; it is considered to be the cleanest fuel etc. Reducing the consumption of fossil fuels emerges from the need to reduce emissions of greenhouse gases, especially $CO_2$, and also due to limited oil resources worldwide. For reducing carbon emissions, European Commission established that renewable energy can achieve a percentage of 20% of all energy sources until the end of 2020 (Huising et al., 2015; Rusu, 2007).

Researches continue to advance in the transport sector, many papers being published on the decrease of fuel consumption of vehicles (Chiriac and Descombes, 2010; Kumar et al., 2008; McCormick, 2007; Rakosi et al., 2010). In the same area lies the present paper, proposing solutions to reduce vehicle fuel consumption by reducing their weight.

## 2. Environmental problems of the transport sector

The European Environment Agency has recently published a study on the evolution of pollution in Europe (EEA, 2012). From this study it results that the transport sector takes the first place on emissions of greenhouse gases before other sectors such as: industrial, residential, commercial and other sectors (Fig. 1). Within the transport sector in Europe, auto transport is the main responsible for the increase of emissions of greenhouse gases, especially $CO_2$. During 1990 and 2009 the increased pollution at European level has contributed to the growth of greenhouse effect with 27%. As reflected in the new EEA analysis, in the EU, in 2010 compared to 2009, the burning of fossil fuels was responsible for an increase of over 100 million tons of $CO_2$. The solution to solve this situation is to reduce the consumption of gasoline and diesel fuels by encouraging the use of cars with alternative propulsion or by reducing the weight of cars with conventional engines. Under this aspect, alternative propulsion cars in 2009 represented only 5% of European car park and only 0.02% there were electric cars.

The automotive industry will face major challenges in the next 10-20 years. To be competitive, it is essential to create new ecological and safe cars (Carlsson et al., 2010). In the following period the automotive industry must be able to produce both types of engines (conventional and different new propulsions) in the same production system. An increased collaboration in research and development activities is now imperative both between the automotive industry and universities, and between the industry and research institutes. An increase in the use of virtual instruments, for rapid analysis and optimization of manufacturing processes, is considered to be of great importance in this context.

The major objectives of the auto industry in the next 10 years are:

- reducing $CO_2$ emissions and other emissions from vehicles and other equipment, creating the conditions for the production of innovative, environmentally friendly and safe vehicles;
- significantly reducing (about 30%) the environmental impact of the production processes.

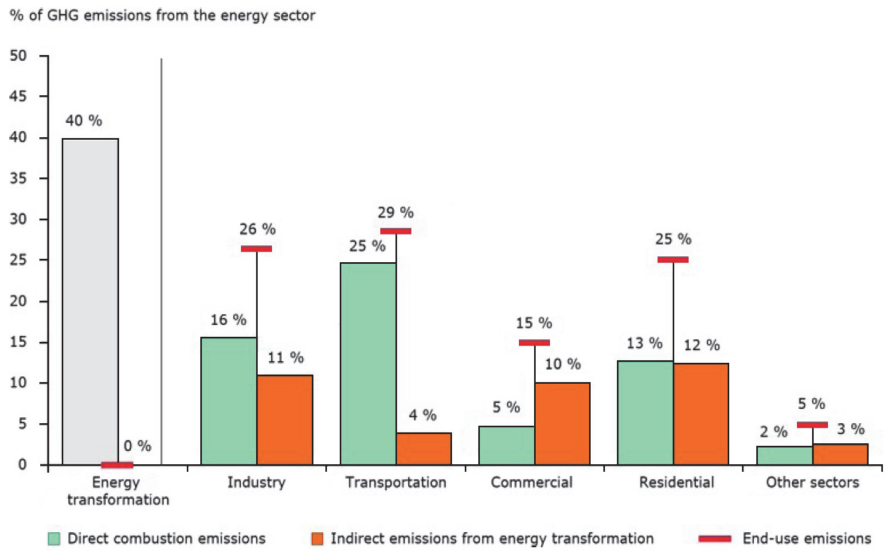



**Fig. 1.** The situation of greenhouse gases emissions in the EU in 2010 (EEA, 2012)

Fulfilling the product requirements such as smaller weight as well as the increase of the passive safety of vehicles, require new or improved materials and manufacturing technologies. New methods of forming and assembly must offer: environmental protection, safety, quality, cost reduction. Among the new methods that meet these requirements the followings can be mentioned: 3D roll forming, roll hemming, electromagnetic forming. Summarizing the problems of the transport sector, the author has identified three ways of reducing $CO_2$ emissions, as shown in the diagram from Fig. 2. It is observed that the direction that can provide immediate results is the replacement of heavy materials with lighter materials (or develop other new light materials) and the introduction of new technologies for processing lightweight materials.

Electromagnetic forming is an advanced processing method that can be applied to plastic deformation and joining and it is considered by many authors (Daehn, 2006a; Seth et al., 2005) an environmentally friendly technology.

### 3. Electromagnetic forming - one of the solutions

*Electromagnetic forming* (*EMF*) is one of the most modern cold working technologies, with high energies and speeds, which was rapidly developed due to its multiple advantages, even for the environment (Daehn, 2006b, 2006c; Padmanabhan, 1997; Seth, 2006):

- low energy consumption due to *EMF* equipments that don't consume energy at idle running such as classic machines; the entire energy accumulated in capacitor bank is being used in the plastic deformation process;
- reduced manufacturing costs through the possibility of using a single die for metal sheets of different thickness (workpieces), since *EMF* does not require achieving a precise clearance between tools like classical punches and dies;
- smaller manufacturing costs by reducing or eliminating heat treatment operations between forming operations, because the forming degree obtained at *EMF* operation is substantially higher than a conventional deformation;
- increased productivity, because work cadence of electromagnetic equipments can reach about 600 parts/hour, given that there are no mechanical elements in motion, as it happens in conventional presses and dies that have mechanical inertia (ram, punch or other elements);
- ensuring indicators of quality, precision, safety and environment for electromagnetic formed or joined parts.

The principle of metal forming by electromagnetic method is based on the electromagnetic induction law and is illustrated in Fig. 3. According to this law, within an electrically conductive material located in a variable magnetic field a current is induced. The variable magnetic field is obtained by discharging the capacitor bank *CB*, which has the capacitance *C* and was loaded to high voltage *V*, by means of the coil 1. When the spark gap *Sg* is acting, through coil 1 an inductor current $i_1$ will pass while through the flat metal sheet 2 an induced current $i_2$ will circulate in the opposite direction. Due to the rejection of the two opposite currents a magnetic pressure is created and plastically deforms workpiece 2 according to the die shape, if the generated pressure exceeds the yield strength of workpiece material. Generally, the force of interaction with an induction magnetic field $\vec{B}$ acting on an element of conductor $d\vec{l_2}$ covered by electric current $i_2$ is calculated (Luca, 2000) with the Eq. (1):

$$d\vec{F} = i_2 \cdot d\vec{l_2} \times d\vec{B} \quad (1)$$

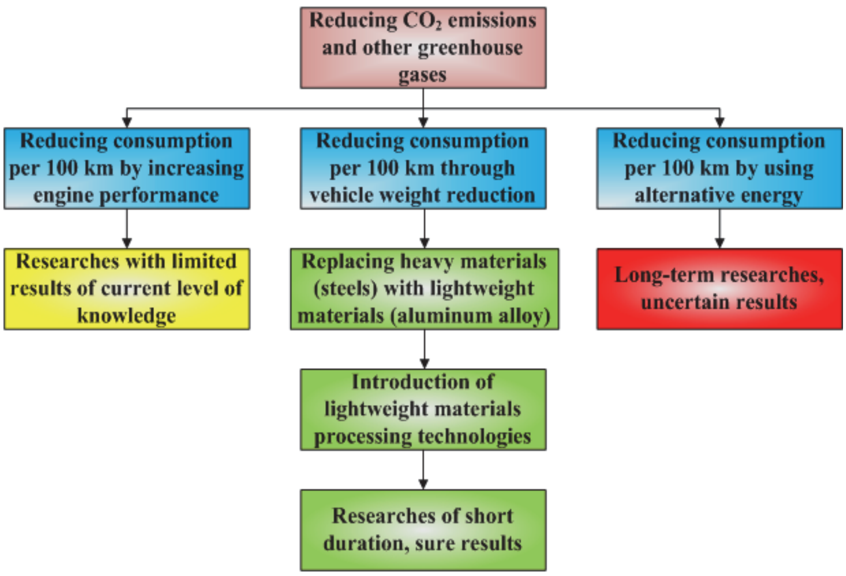



**Fig. 2.** Solutions identified for reducing $CO_2$ emissions

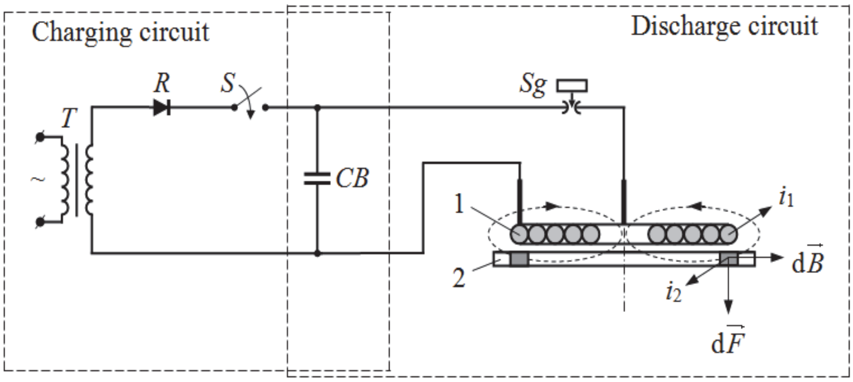



**Fig. 3.** The principle of electromagnetic forming method

The relationship (1) shows that the force $\mathrm{d}\vec{F}$ is perpendicular to both the magnetic induction vector $d\vec{B}$ and $d\vec{l_2}$, which is a vector having the same sense with current and equal module with $dl_2$. Processing equipments by *EMF* are composed of two basic circuits:

- charging circuit, comprising of the current source, the high voltage transformer *T*, the rectifier *R*, the switch *S* and the capacitor bank *CB*;
- discharge circuit, consisting of the capacitor bank *CB*, the spark gap *Sg* and coil 1.

The most important parameters, in the case of manufacturing parts by *EMF*, are the discharge current that passes through the coil $i_1$ and the magnetic induction *B* produced by the coil, according to the Eqs. (2) and (3):

$$i_1(t) = I_{max} \cdot e^{-\alpha t} \sin \omega t \qquad (2)$$

$$B(t) = B_{max} \cdot e^{-\alpha t} \sin \omega t \qquad (3)$$

where: $I_{max}$ is the maximum value (amplitude) of the discharge current; $\alpha$ represents the damping coefficient; $\omega$ is the current pulsation; $B_{max}$ is the maximum value of magnetic induction.

At the beginning, *EMF* has been applied to formed axisymmetric parts (Kleiner et al., 2005). *EMF* was applied to three types of processes, defined by the arrangement of the tool (the coil) and workpiece: tube compression, sheet metal forming and tube expansion. These processes are schematically shown in Fig. 4.

## 4. Applications of electromagnetic forming

The development of advanced technologies for plastic deformation, like *EMF*, ensures a significant reduction of energy consumptions and accordingly an increase of energy efficiency of equipments (economic benefits) along with a reduction of the environmental impact of the process by reducing, per unit of obtained product, specific greenhouse gas emissions, especially carbon dioxide (environmental benefit). Numerous researches show interest and efforts to expand the application of *EMF* technology in industrial manufacturing, including the automotive industry.

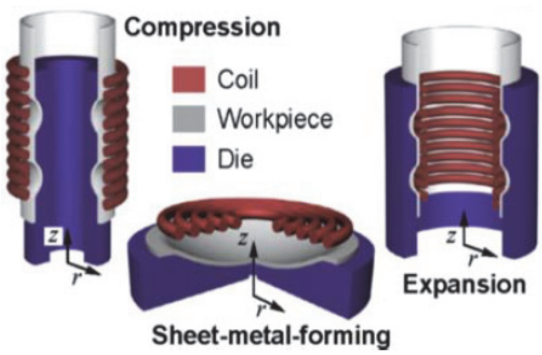



**Fig. 4.** Types of deformation obtained by *EMF* (Kleiner et al., 2005)

Over 10 years ago, the potential of the application of *EMF* in multi-stage stamping of car doors was investigated (Daehn et al., 1999). The first experiments have shown that *EMF* can overcome limitations imposed by low formability and small ductility of aluminum alloys. These experiments have also shown that *EMF* can be applied to other workpieces, of larger size, for the manufacture of asymmetric parts (e.g., car doors).

The paper (Park et al., 2005) shows that reducing vehicle weight is one of the most important solutions for improving fuel efficiency from automobiles. Replacing steel with low density materials such as aluminum, magnesium, plastics etc. is a good solution for reducing vehicle weight. Among lightweight materials, the use of high strength aluminum alloys in the automotive industry is growing every year. But parts obtained by deformation from aluminum alloys need to be joined with other parts that have different cross sectional shapes or are made of different materials. Currently several methods are known for joining elements of automotive body: resistance spot welding by contact, laser welding, welding with inert gases. The three methods, that are large energy consumers and polluters, have in common the following disadvantages: local heating of the material up to the melting point, which leads to appearance of a heat influenced zone; the joined elements are distorted and have a weaken resistance; the joint between different materials raises serious problems. *EMF* represents in this case a solution, because there is no heat involved in the electromagnetic joint and there are no specific welding problems. The experimental tests in the paper aimed to apply electromagnetic joint for elements of the automotive body (Fig. 5). The results showed that two different materials, an extruded tube from 6063-T5 aluminum and a high-strength steel tube (used for manufacture elements of auto body), have been successfully joined by *EMF*, without the need of a welding operation.

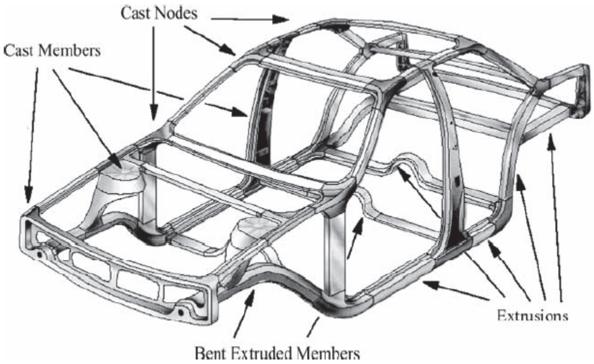



**Fig. 5.** The elements of a car body (Park et al., 2005)

Another paper (Golovashchenko, 2007) shows that the decrease in vehicle weight can be achieved by using aluminum alloys for the car body construction. A problem of the aluminum alloys, in general, is their low formability, which makes them difficult to process though plastic deformation. Promoting their use in the production of car body panels will be possible by improving the formability of aluminum alloys. Presently, few methods are known to increase the formability of these alloys: cold forming with the application of intermediate heat treatment operations (annealing recrystallization), integral hot forming, and forming by bringing aluminum alloys in conditions of superplasticity.

The three methods, large energy consumers and polluters, have in common the following disadvantages: they require heating the material in order to deform, which leads to increasing costs of the plastically deformed part; thin workpieces (sheet metal) remain a problem because they cool quickly and must be deformed under isothermal conditions, which complicates the process and makes it more expensive; the used lubricants do not retain their properties at high temperatures, which makes them inefficient. Another shortcoming is related to the additional operations to be performed for cleaning lubricant before heating and reapplication before forming operation. A solution to remove heating workpieces before forming, as well as eliminating lubrication, is the *EMF* which causes an increase in formability for aluminum alloys, equivalent to that obtained with the help of temperature. Experimental tests have shown that two aluminum alloys (6111-T4 and 5754 marks), which are used for automotive body panels (Fig. 6), have been successfully processed by *EMF*, without the need of additional consume (costs) of energy for heating, lubricants and the related working operations.

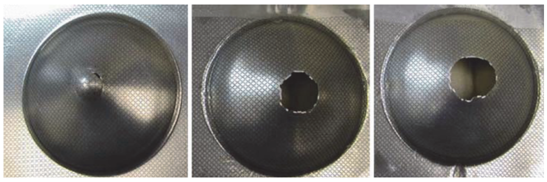


**Fig. 6.** Samples of 6111-T4 deformed by *EMF* (Golovashchenko, 2007)

Risch et al. (2008) promotes the concept of reducing fuel consumption in the transport sector and $CO_2$ emissions in two ways: design optimization of automotive components and choice of lightweight materials such as aluminum. The authors propose the use of aluminum alloys, such as the 5xxx family, for replacing steel from car bodies, due to their advantages: small density and high strength. There is already an obvious dynamics in terms of increasing the quantity of aluminum within the European automotive industry, as shown by Fig. 7.

It is known that the formability of 5xxx aluminum alloys is lower than that of the steel currently used in car body. There are elements that require a large number of deep drawing operations or cannot be achieved by conventional deep drawing. The authors propose for such situations the application of a hybrid technology, which combines traditional deep drawing with *EMF*. Experimental investigations have shown the possibilities of hybrid technology, which has been successfully applied to the deformation of the car door handle.

Researches carried out recently (Furrer, 2008) were aimed to establish the conditions for optimizing *EMF* operations and increase the quality of automotive parts (Fig. 8). Results were obtained in an EU funded project, which has sought to apply electromagnetic forming to the manufacture of lighter vehicles, a new and decisive phase in the shift to manufacture of ecological cars. Experiments were designed to be used directly by the auto industry, the application of *EMF* for auto body elements having the role of reducing vehicle weight and lowering $CO_2$ emissions. This concept is part of the modern manufacturing strategies of green cars, without additional costs for the producer or consumer.

Researches concerning the application of *EMF* to obtain parts for the automotive industry are also carried out at the Laboratory of Unconventional Technologies of Plastic Deformation from the Faculty of Materials Science and Engineering of Iasi. In a research project funded by the Romanian Government (Luca et al., 2006), *EMF* experiments were conducted for several types of aluminum alloy parts, in order to replace the steel parts that were weighed more from the structure of vehicles destined for municipal activities.

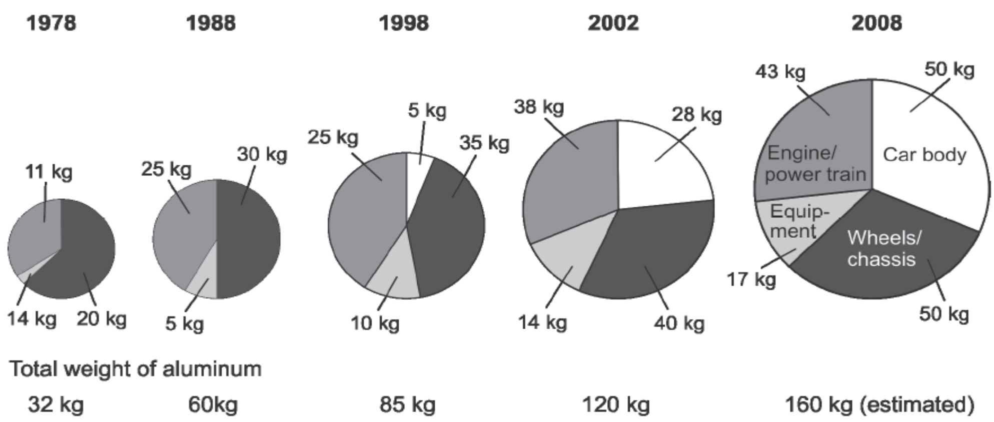



**Fig. 7.** The evolution of aluminum use in the automotive industry in Europe (Risch et al., 2008)

**Fig. 8.** Car body deformed by *EMF* (Furrer, 2008)

Fig. 9 shows the *EMF* system from the laboratory and three types of aluminum alloy parts (cover type) achieved in order to reduce vehicle weight. Operating parameters of the equipment used for the experimental tests are: maximum charging voltage of the capacitor bank - 10 kV; capacitance of the capacitor bank - 4×50 μF.

In order to establish the necessary energy for a specific plastic deformation operation we have to know the required value of the discharge current that though magnetic induction and deformation pressure can modify the shape and size of the workpiece. Considering the plasticity characteristics of the part's material and its size, the amount of current required is determined from the following condition (Eq. 4):

$$i_{req} \geq \frac{d_1}{N}\sqrt{-\frac{2}{\mu}\sigma_y \ln\left(1-\frac{t}{d}\right)} \tag{4}$$

where: $d_1$ is the diameter of the coil;
$N$ is the number of turns;
$\mu$ is the magnetic permeability of the part;
$\sigma_y$ is the yield strength of the material;
$t$ is the thickness of the workpiece;
$d$ is the diameter of the part.

Plastic deformation of the part is at its maximum when the discharge current reaches the highest value, this being given (Luca, 2012) by the Eq. (5):

$$i_{req} \equiv I_{max} = V\sqrt{\frac{C}{L}}\left(1-\frac{\pi R}{4}\sqrt{\frac{C}{L}}\right) \tag{5}$$

where: $V$ and $C$ are the charging voltage and correspondingly the capacitance of the capacitor bank; $L$ and $R$ are the inductance and respectively the resistance of the discharge circuit.

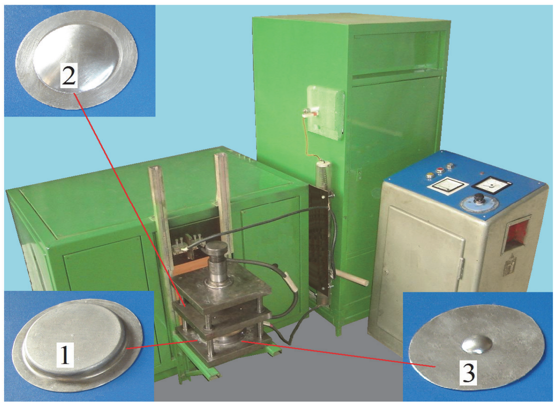



**Fig. 9.** *EMF* equipment used for the experiments and obtained parts

From Eqs. (4) and (5) we determine the minimum voltage at which the capacitor bank must be charged (Eq. 6):

$$V_{min} \equiv V \geq \frac{\frac{d_1}{N}\sqrt{-\frac{2}{\mu}\sigma_y \ln\left(1-\frac{t}{d}\right)}}{\sqrt{\frac{C}{L}}\left(1-\frac{\pi R}{4}\sqrt{\frac{C}{L}}\right)} \tag{6}$$

Considering the minimum value of the capacitor bank's voltage, the required energy is calculated by the Eq. (7):

$$E_{req} = \frac{C \cdot V^2}{2} \tag{7}$$

The parts obtained by *EMF* within these studies, shown in more detail in Fig. 9, require a much lower consumption of electrical energy compared to producing these parts by classical technology (drawing). Table 1 shows the calculation of the electrical energy consumed for plastic deformation of part 1 by two different technologies.

This major drop in electricity consumption for manufacturing parts by *EMF* is explained by the fact that in this procedure all the energy accumulated in capacitor bank is used for plastic deformation of the workpiece.

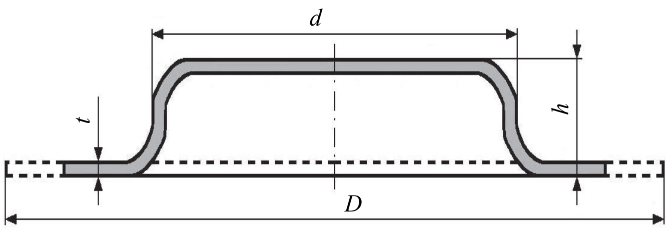
In *EMF* equipment does not exist moving machine elements such as ram, connecting rod, flywheel from a classical press, there is no energy consumed like the idle running of a press where the electric motor operates continuously and there is no energy lost through friction as it happens in a press where friction is present in the guides, bearings etc.

## 5. Conclusions

The studies of this paper show that a pragmatic way to decrease of $CO_2$ emissions and other greenhouse gases is to reduce vehicle fuel consumption, which can be achieved by reducing their weight. This objective can be achieved by replacing heavy materials of the vehicle's body such as steel, with lightweight materials such as aluminum. The condition for light materials is to have a high strength in order to satisfy the requirement of traffic safety vehicles. This type of material is hard to work by plastic deformation because it possesses a low formability. Present and future researches need to find solutions for processing lightweight materials with high-strength.

An unconventional technology of plastic deformation, based on the electromagnetic method, seems to respond to these requirements.

**Table 1.** Energy consumption calculations for the deformation of the part 1

| ***Variant 1: Electromagnetic forming*** | ***Variant 2: Classic deformation (drawing)*** |
|---|---|
| Schematic drawing of the part 1<br>$d = 80$ mm   $t = 1$ mm<br>$D = 110$ mm   $h = 10$ mm<br>$m = \frac{d}{D} = 0.727$<br>Material: Al Mn0.5 Mg0.5<br>($\sigma_y = 158.781$ MPa; $\sigma_u = 175.072$ MPa) | <br> |
| ✤ The required discharge current:<br>$i_{req} = 25.204$ kA (Eq. 4)<br>where $d_1 = 80$ mm; $N = 9$; $\mu = 1{,}00002$<br><br>✤ Minimum voltage charge of *CB*:<br>$V_{min} = 2831$ V (Eq. 6)<br>where $\begin{cases} C = 200 \cdot 10^{-6} \text{ F;} \\ L = 2.122 \cdot 10^{-6} \text{ H;} \\ R = 10.896 \cdot 10^{-3}\ \Omega \end{cases}$<br><br>✤ The required deformation energy:<br>$E_{req} = 841$ J (Eq. 7)<br>where $C = 200 \cdot 10^{-6}$ F; $V = 2900$ V<br><br>✤ The equivalence between the amount of energy transferred by a process that gives or receives a power of one watt for one hour, and the energy is given by the relation:<br>1 Wh = 3600 J<br><br>✤ Electric energy consumed for a part electromagnetically deformed (Batygin and Daehn, 1999):<br>$E_{elmag} \equiv E_{req} = \frac{841 \text{ J}}{3600} = 0.23361$ Wh | ✤ Drawing force (Iliescu, 1990):<br>$F = k \cdot \pi \cdot d \cdot g \cdot \sigma_u = 24200.216\ N$<br>where $k = f(m) \rightarrow k = 0.55$ (coefficient)<br><br>✤ The work of deformation:<br>$W = \lambda \cdot F \cdot h = 162.141\ J$<br>where $\lambda = f(m) \rightarrow \lambda = 0.67$ (coefficient)<br>✤ Output power:<br>$P_{out} = \frac{W \cdot n}{60 \cdot 10^3} = 0.405$ kW<br>where $n = 150$ d.s./min $\rightarrow$ press EEP − 15<br>✤ The required power:<br>$P_{req} = a \cdot \frac{P_{out}}{\eta} = 1.134$ kW<br>where $\begin{cases} a = 1.2...1.4 \rightarrow a = 1.4 \\ \quad (coefficient) \\ \eta = 0.5...0.7 \rightarrow \eta = 0.5 \\ \quad (average\ efficiency) \end{cases}$<br>✤ Electric energy consumed for one hour:<br>$E_h = P_{req} \cdot T = 1.134$ kWh<br>where $T = 1$ hour<br>✤ Electric energy consumed for a part classically deformed:<br>$E_{classic} = \frac{E_h}{N} = 0.01134$ kWh<br>where $N = 100$ parts |
| Ratio between electric energy consumed for a part classically / electromagnetically deformed:<br>$\frac{E_{classic}}{E_{elmag}} = \frac{0.01134\ kWh}{0.23361 \cdot 10^{-3}\ kWh} = 48.545$ | |

*EMF* is a method that involves high energies and speeds of work and has a number of advantages, such as: it can be applied to plastic deformation of different metals, such as aluminum, copper, steel, gold, silver and so on. The required tools are simple and inexpensive; the equipment can be used for various applications such as deformation of metal sheets, expansion or compression of metal tubes, powder pressing, welding and other applications; the technology is clean, it does not dirty the parts, it requires no lubrication, so it is considered environmentally friendly.

Experimental tests and calculations presented in this paper demonstrate a decrease of about 50 times in electric energy consumption for all three parts obtained through *EMF* compared to the case where the parts would be achieved by conventional technology with mechanical or hydraulic presses.

## References


Batygin Y.V., Daehn G.S., (1999), *The Pulse Magnetic Fields for Progressive Technologies, Chapter 5*, Kharkov, Columbus, On line at: http://www.matsceng.ohio-state.edu/~Daehn/yuribook/.

Bostan I., (2016), Pro sustainable development: the influence of the law of entropy on economic systems, *Environmental Engineering and Management Journal*, **15**, 2429-2432.

Boutin J.-P., Gervasoni G., Hlep R., Seyboth K., Lamers P., Ratton M., McCormick K., Mundaca L., Plepys A., (2007), Alternative energy sources in transition countries. The case of bio-energy in Ukraine, *Environmental Engineering and Management Journal*, **6**, 3-11.

Carlsson A., Hjelm S., Holmgren B., Malmsköld L., Granström M., Svenningstorp J., Wik A., (2010), *2020 Sustainable Manufacturing Systems Capable of Producing Innovative Environmentally Friendly and Safe Products, R&D Program Proposal*, Third Edition, On line at: http://www.vinnova.se/upload/dokument/Verksamhet/Transporter/FFI/Sustainable%20Manufacturing%20Systems%20RD%20Program%20Third%20Edition%20Jan%202010.pdf.

Chiriac R., Descombes G., (2010), Fuel consumption and pollutant emissions reduction for diesel engines by recovery of wasted energy, *Environmental Engineering and Management Journal*, **9**, 1335-1340.

Corabieru P., Corabieru A., Vasilescu D.D., (2015), Research and trends in product life cycle management in the context of sustainable development, *Environmental Engineering and Management Journal*, **14**, 205-212.

Daehn G.S., (2006a), *High Velocity Metal Forming*, In: *ASM Handbook*, Volume 14 B, Metalworking: Sheet Forming, Semiatin S.L. (Ed.), ASM International, Ohio, 405-418.

Daehn G.S., (2006b), Electromagnetic forming demonstrations, On line at: http://www.matsceng.ohio-state.edu/~Daehn/hyperplasticity/overview_presentation/sld001.htm.

Daehn G.S., (2006c), High velocity sheet metal forming: State of the Art and Prognosis for Advanced Commercialization, On line at: http://www.matsceng.ohio-state.edu/~Daehn/hyperplasticity/stateofartrept/index.html.

Daehn G.S., Vohnout V.J., Datta S., (1999), *Hyperplastic Forming: Process Potential and Factors Affecting Formability*, Proc. of the 1999 MRS Fall Meeting, Boston, Volume 601, 247.

EEA, (2012), Households and industry responsible for half of EU greenhouse gas emissions from fossil fuels, Published: Dec 20, 2012, On line at: http://www.eea.europa.eu/highlights/households-and-industry-responsible-for.

Fortuna M., Simion I.M., Gavrilescu M., (2012), Assessment of sustainability based on LCA–case of woody biomass, *Cellulose Chemistry and Technology*, **46**, 493-510.

Furrer P., (2008), Electromagnetic forming shapes eco-friendly vehicles, ALCAN Technology & Management AG, Automotive technology, Result from the EU funded GROWTH programme, Community Research and Development Information Service – CORDIS, On line at: http://cordis.europa.eu/fetch?CALLER=MSS_CH_OFFR_EN&ACTION=D&DOC=21&CAT=OFFR&QUERY=0122757fa5e5:cc60:2c400bfe&RCN=4246.

Gavrilescu M., (2008), Biomas power for energy and sustainable development, *Environmental Engineering and Management Journal*, **7**, 617-640.

Gavrilescu D., (2008a), Energy from biomass in pulp and paper mills, *Environmental Engineering and Management Journal*, **7**, 537-546.

Gavrilescu D., (2008b), Carbon dioxide generation – Implications for Romanian pulp and paper industry, *Environmental Engineering and Management Journal*, **7**, 111-117.

Golovashchenko S.F., (2007), Material formability and coil design in electromagnetic forming, *Journal of Materials Engineering and Performance*, **16**, 314-320.

Huisingh D., Zhang Z., Moore J.C., Qiao Q., Li Q., (2015), Recent advances in carbon emissions reduction: policies, technologies, monitoring, assessment and modeling, *Journal of Cleaner Production*, **103**, 1-12.

Iliescu C., (1990), *Cold-Pressing Technology* (*Studies in Mechanical Engineering*), Volume 9, Elsevier Science & Technology, Oxford.

Kleiner M., Beerwald C., Homberg W., (2005), Analysis of process parameters and forming mechanisms within the electromagnetic forming process, *CIRP Annals - Manufacturing Technology*, **54**, 225-228.

Kumar M.R., Govind P., Parida M., (2008), Smoke emissions from diesel vehicles: A case study, *Environmental Engineering and Management Journal*, **7**, 103-110.

Lakó J., Hancsók J., Yuzhakova T., Marton G., Utasi A., Rédey Á., (2008), Biomass – A source of chemicals and energy for sustainable development, *Environmental Engineering and Management Journal*, **7**, 499-509.

Luca D., (2000), *Research and contributions regarding plastic processing by the electromagnetic forming proceeding*, PhD Thesis, Gheorghe Asachi Technical University of Iasi.

Luca D., Gheorghiu D., Zaharia L., Bejinariu C., (2006), *The assimilation in manufacturing of sheet metal parts for automotive industry formed by the electromagnetic* *process*, Research Report, INVENT Program, Iasi-Bucharest, Romania.

Luca D., (2012), A numerical modelling: opened perspectives to increase the performance of the electromagnetic forming processes, *International Journal of Numerical Modelling: Electronic Networks, Devices and Fields*, **25**, 15-23.

Mateescu C., Băran Gh., Băbuţanu C.A., (2008), Opportunities and barriers for development of biogas technologies in Romania, *Environmental Engineering and Management Journal*, **7**, 603-607.

McCormick K., (2007), Ecological economics and transport systems, *Environmental Engineering and Management Journal*, **6**, 21-25.

Mellor S., Hao L., Zhang D., (2014), Additive manufacturing: A framework for implementation, *International Journal of Production Economics*, **149**, 194-201.

Mofijur M., Rasul M.G., Hyde J., Azad A.K., Mamat R., Bhuiya M.M.K., (2016), Role of biofuel and their binary (diesel–biodiesel) and ternary (ethanol–biodiesel–diesel) blends on internal combustion engines emission reduction, *Renewable and Sustainable Energy Reviews*, **53**, 265-278.

Padmanabhan M., (1997), *Wrinkling and springback in electromagnetic sheet metal forming and electromagnetic ring expansion*, MSc Thesis, The Ohio State University.

Park Y.-B., Kim H.-Y., Oh S.-I., (2005), Design of axial/torque joint made by electromagnetic forming, *Thin-Walled Structures*, **43**, 826-844.

Păsculete E., Condrea F., Rădulescu C., (2007), Hydrogen and sustainable energy. Research for hydrogen production, *Environmental Engineering and Management Journal*, **6**, 45-49.

Risch D., Gersteyn G., Dudzinski W., Beerwald C., Brosius A., Schaper M., Tekkaya A.E., Bach F.-W., (2008), *Design and Analysis of a Deep Drawing and In-Process Electromagnetic Sheet Metal Forming Process*, Proc. of the 3rd International Conference on High Speed Forming, Dortmund, On line at: https://eldorado.tu-dortmund.de/bitstream/2003/27089/1/11.pdf

Rusu I., (2007), Development trends of cold plasma reactors in the global context of carbon emission reduction, *Environmental Engineering and Management Journal*, **6**, 211-217.

Rakosi E., Manolache Gh., Talif S., Roşca R., (2010), Solutions for reducing fuel consumption and pollution of automotive spark ignition engines, *Environmental Engineering and Management Journal*, **9**, 1351-1355.

Seth M., Vohnout V.J., Daehn G.S., (2005), Formability of steel sheet in high velocity impact, *Journal of Materials Processing Technology*, **168**, 390-400.

Seth M., (2006), *High velocity formability and factors affecting it*, PhD Thesis, The Ohio State University.

Torretta V., Capodaglio A.G., (2017), Strategic environmental assessment: a critical review of procedural soundness and reliability, *Environmental Engineering and Management Journal*, **16**, 105-112.

Wu D., Rosen D.W., Wang L., Schaefer D., (2015), Cloud-based design and manufacturing: A new paradigm in digital manufacturing and design innovation, *Computer-Aided Design*, **59**, 1-14.

Yue D., You F., Snyder S.W., (2004), Biomass-to-bioenergy and biofuel supply chain optimization: Overview, key issues and challenges, *Computers & Chemical Engineering*, **66**, 36-56.