Abstract:
Based on the use of innovative materials it is necessary to find the suitable forming technologies for specific material properties. The Fraunhofer Institute for Machine Tools and Forming Technology IWU has been developing new forming technologies for applications of sheet metal and tubes for many years. In addition to the conventional forming technologies, electromagnetic forming (EMF) offers the possibility to shape new geometries by very small energetic power consumption.

The most important application of EMF is joining by compression of tubular work-pieces. Electromagnetic forming makes use of the interactions between materials with good electrical conductivity and high power magnetic fields created by a pulsed current flowing through a tool coil. The target-oriented exploitation of the process specific advantages of EMF for the economic production of parts is an important aim of our research.

Keywords: electromagnetic forming, sheet metal, tubes, magnetic field, coil

1. INTRODUCTION
Electromagnetic Forming (EMF) is a metal working process that relies on the use of electromagnetic forces to form metallic work-pieces at high speeds. In this process, a transient electric current flows through a coil due the sudden discharge of a capacitor bank via high-speed switches. The coil current induces a magnetic field and a current in the nearby conductive work-piece (sheet metal, tube or profile) which is directed opposite to the coil current the current. The magnetic field, together with the eddy current, induces Lorentz forces that drive the deformation of the work-piece. In an EMF process, the material can achieve velocities in the order up to 100 m/s in less than 0.1 ms. EMF is expected to help overcoming some formability barriers that prevent more widespread use of materials such as aluminum in lightweight structural applications. Depending on the geometry, the arrangement of the work-piece and the tool coil, this forming principle can be used for the compression and expansion of tubes or other hollow profiles as well as for the forming of flat or 3-dimensionally preformed sheet metals [1, 2]. A more detailed description of the process principle is given in [3].

The typical setup for sheet metal forming consists of a spirally wound tool coil, above which the work-piece and the die, respectively, are positioned. Tubes or profile cross sections can be reduced by means of a compression coil or widened by means of expansion coils. In any case the work-piece is formed in the direction away from the tool coil. Depending on the forming process the coil is positioned inside or outside the tubular component. Thereby, the forming machine can be represented in a simplified model by an equivalent circuit consisting of a capacitor C, an inner inductance L, and an inner resistance R [3]. The main forming principles are illustrated in the Figure 1.

The electromagnetic forming and joining brings following advantages compared to many conventional forming technologies as e.g. deep drawing:

- Forces act contactless on the work-piece and accordingly any damaging or contamination of the work-piece surface is prevented.
- High strain rates ($10^4$ s$^{-1}$) during the forming operations allow higher strains in many materials without failure [4]. Thus, an extension of forming limits can be achieved.
Integration of additional technologies (cutting, joining) is possible, so that process chains can be shortened and production becomes more efficient and economic.

![Technology variants of EMF](image)

**Fig. 1:** Technology variants of EMF

## 2. FORMING TECHNOLOGIES

### 2.1 Sheet metal forming

Besides conventional forming Fraunhofer IWU develops high innovative forming technologies. EMF represents one of these new methods of forming. Due to the electric conductivity and the low comparatively tensile strength of aluminium alloys EMF can be beneficially applied for these materials. Thereby, flat or preformed sheets can be formed by accordingly adapted coils. This allows even the integration of the EMF technology into a conventional forming process as e.g. a deep drawing operation. In the Figure 2 different examples of our research programs are presented. The basic tests of rectangular geometry allowed determining forming limits. The results could be applied for forming the door handle. EMF offers the possibility of forming a wide range of design elements. Several industrial applications have been developed with the industrial partners. One example is the Audi brand name with four rings. The flat coil substitutes the punch and can be applied for manufacturing different components. Only the die has to be adapted to the individual forming task. The application of flat coil allows forming of different structure elements, provided that the overall dimensions are similar.

![Sheet metal forming](image)

**Fig. 2:** Sheet metal forming
2.1 Forming of tubes and profiles

EMF of tubes and hollow profiles can be divided into two variants (Figure 1). The first one the electromagnetic compression reduces the diameter of tube using a coil surrounding the work-piece. In most cases mandrels or dies are used to ensure geometric tolerances, but die-less forming is also possible. Occasionally split mandrels or dies are used to separate these and the work piece after forming. EMF of tubular structures shows numerous benefits over conventional tube forming processes. EMF can compress tube of non-rotationally symmetric cross sections and due to the high velocities and forces, spring-back effects are minimized. Two examples of electric compression are illustrated in Figure 3.

The second variant is the electromagnetic expansion. Thereby, the diameter of tube expands using the coil inside the tube. The maximum expansion is limited due the die.

![Fig. 3: Examples of electric compression](image)

2.1 Joining and cutting

Apart from mere forming operations, EMF can be used for joining by forming similar and dissimilar material combinations. In fact joining profile shaped parts has been identified as the most promising process variant for industrial applications. Since only one joining partner needs to be electrically conductive, the potential material combinations include metal / metal as well as metal / non-metal hybrid structures (e.g. aluminium – fibre reinforced plastic-connections, copper-ceramic-connections, metal-glass-connections and others). The resulting joints can be based on interference-fit, form-fit, or – in case of metal / metal connection – even on metallic bonding realized by magnetic pulse welding.

Some examples of joining with different materials (copper/aluminium; carbon fibre/aluminium; aluminium/aluminium; copper/carbon fibre) are illustrated in the Figure 4. Applications of field shapers enable focusing the forces to a smaller diameter and/or length compared to the tool coil. This allows using one and the same tool coil for different forming and joining tasks. Moreover, the application of a field shaper can contribute to improving the coil lifetime, because the force acting on the coil are smaller compared to a setup without field shaper. Accordingly, the use of a field shaper supports the joining of tubes with greater wall thickness, which typically requires high forces. The joining of tube and solid matter is demonstrated on the shaft-hub connection in Figure 5 [5].

Cutting operations are carried out using a tool coil and a suitable cutting die. The resulting cutting edge quality excels due to the extremely low burr formation. Two examples (aluminium and high strength steel) of cutting are illustrated in Figure 6. For more details about this application variant, please refer to [6].
3. **EQUIPMENT**

For experimental investigations the following equipment is available on Fraunhofer IWU:

- Pulsed power generator PS103-25 Blue Wave by PST Products featuring
  - a maximum capacitor charging energy of 103 kJ,
  - a maximum capacitor charging voltage of 25 kV,
  - a stepwise adjustable capacitance of 25.6 µF to 320 µF,

- Pulsed power generator by Siemens featuring
  - a maximum capacitor charging energy of 100 kJ,
  - a maximum capacitor charging voltage of 21 kV,
  - a capacitance of 450 µF

4. **ACKNOWLEDGEMENT**

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LITERATURE


