

ELECTROMAGNETIC FORMING



CONTACT-FREE AND FAST

Electromagnetic forming (EMF) is a high-speed forming technology that can be applied for shaping as well as for joining and cutting of sheet metal and profile-shaped workpieces made of an electrically conductive material.

The force application is realized via the energy density of pulsed magnetic fields and does not require any physical contact of tool (inductor) and workpiece. As a consequence of the force application, the workpieces are accelerated up to velocities of several hundreds of meters per second, resulting in strain rates in the magnitude of up to $10,000 \text{ s}^{-1}$. The forming, joining or cutting process is typically completed within some tens up to one or two hundreds of microseconds.

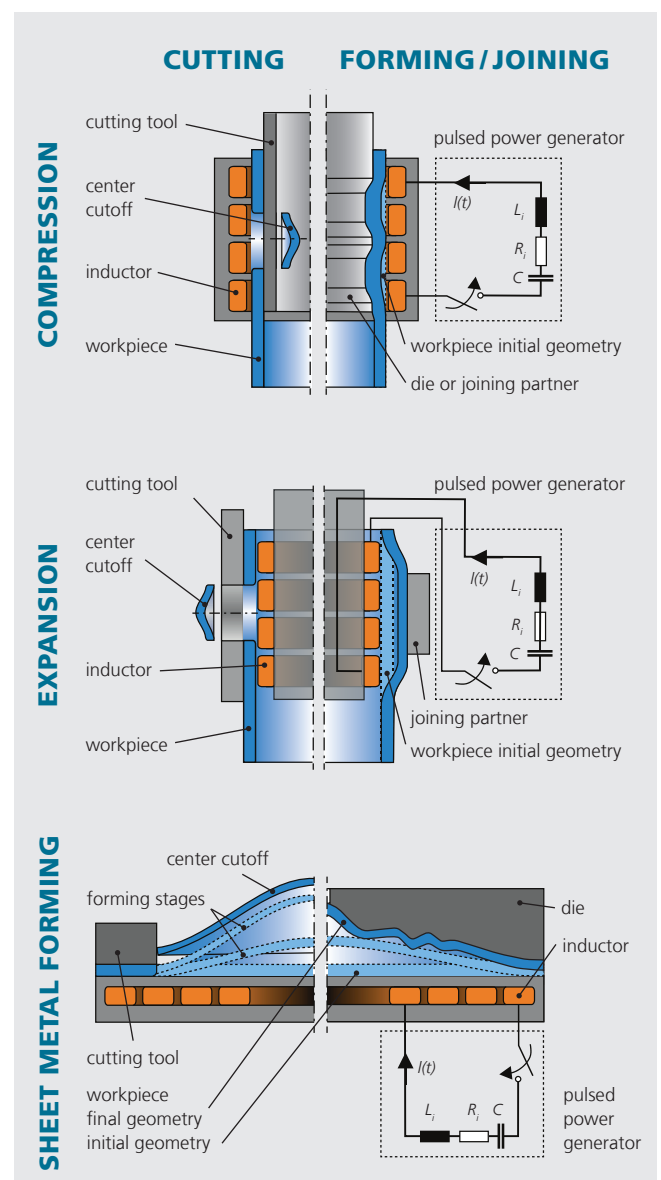
The setup for EMF consists of the pulsed power generator, the inductor including a fieldshaper, if applicable, the workpiece and application-dependent further tool components such as form-defining dies, cutting tools or joining partners. Depending on the geometry and the alignment of tool and workpiece, three process variants can be distinguished. These are

- electromagnetic compression of tubes and hollow profiles by means of an inductor enclosing the workpiece,
- electromagnetic expansion of tubes and hollow profiles by means of an inductor positioned within the workpiece and
- electromagnetic sheet metal forming, for which an inductor is positioned in close proximity of a flat semi-finished part or a preformed component.

Independent of the specific setup, the process is started by charging and subsequently discharging the capacitor of the pulsed power generator. Consequently, a damped sinusoidal current pulse flows through the inductor. This time-dependent current induces a corresponding magnetic field. If there is an electrically conductive workpiece in direct proximity to the inductor, a second oppositely directed current is induced shielding the magnetic field so that the field strength between workpiece and inductor is significantly higher compared to the one on the workpiece surface facing away from the inductor.

The energy density stored in the magnetic field can be regarded as magnetic pressure which can reach maximum values of up to several hundreds of megapascals and causes the acceleration and deformation of the workpiece. The direction of the movement is always targeted away from the inductor.

Depending on the applied further tool components and their interaction with the workpiece, shaping, cutting and joining operations can be distinguished and even combining these applications within one and the same part and process step is possible.





1

KEY ASPECTS OF RESEARCH AND CORE COMPETENCIES

In the field of electromagnetic forming, the Fraunhofer Institute for Machine Tools and Forming Technology IWU offers its clients integrative solutions for manufacturing problems. These focus on aspects of

- process- and technology development,
- tool development and
- product development.

The integrative approach is indispensable in this case here because during EMF the acting loads – i.e. the temporary and local distribution of current, magnetic field and magnetic pressure – as well as the resulting workpiece deformation depend on the chosen process parameters, the properties of the applied machine and tools and the parameters of the workpiece itself.

Process- and technology development

The area of process- and technology development encompasses the accomplishment of numerical and experimental feasibility studies, process analyses and process designs for shaping, joining and cutting operations. Thereby, not only mere EMF procedures, but also process integrations and process chains are regarded, combining EMF with conventional forming technologies. Presupposing a sophisticated choice of technologies, the process-specific advantages complement each other, resulting in an extension of forming limits. Thus, the manufacturing of components, which cannot be produced by any of the technologies individually, becomes possible.

In contrast to conventional forming technologies, in case of EMF not only the typical mechanical process parameters, but also the electromagnetic and sometimes the thermal parameters as well as the mutual interdependencies of these field variables have to be considered. One of the most important

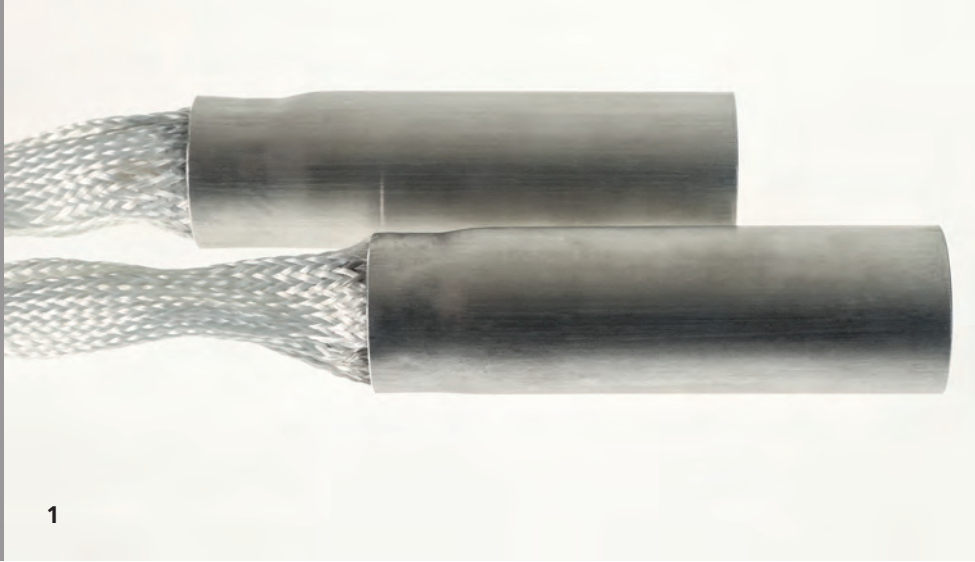
interactions is that the magnetic pressure, which results from the distribution of the magnetic field, causes the workpiece deformation, while the change of the workpiece geometry influences the distribution of the magnetic field and pressure.

Tool development

The Fraunhofer IWU possesses comprehensive expertise regarding the application-specific design of inductors, field-shapers and further tool components as e.g. form defining dies, especially considering mechanical, electrical and electromagnetic aspects. When designing process combinations and integrated EMF-processes, demands of all technologies involved have to be taken into consideration. This means e.g. that the integration of an inductor into a deep drawing tool is possible, but results in much higher demands on the friction resistance of the inductor surface, which is also used for drawing the sheet.

Another research focus of the Fraunhofer IWU lies on the development and provision of strategies for tool design and production which are as generally applicable as possible. The motivation for this research is that the economic exploitation of the potential of EMF in industrial manufacturing is currently hindered by the fact that knowledge about and devices for the tool and process design are not sufficiently available. Thus, simulation strategies are developed as a tool in the inductor design process and decision criteria with regard to the design of the inductor winding, the material choice and the insulation and armoring strategy, etc. are identified at the Fraunhofer IWU in close cooperation with the Chemnitz University of Technology, the Belgium Welding Institute and the University of Gent within the framework of a project funded by the European Commission within the CORNET-Program. The resulting design methodology will be provided for applicants via flow-charts and guidelines for construction and manufacturing of inductors.

1 *Electromagnetically formed design element*



1

Product development

The field of product development comprises the adaptation of the (local) component geometry and/or the applied material within the limits defined by the manufacturing task with the aim of

- optimizing the part performance e.g. considering stiffness or other application-relevant aspects and
- rendering the application-specific advantages of the EMF as much exploitable as possible.

By electromagnetic forming individually designed and task-adapted structures can be realized in order to optimize component properties, e.g. regarding the weight as well as the acoustic behavior. Practically, such structuring elements can increase the component stiffness. Provided that sufficient strength is guaranteed, the wall thickness can then be reduced. At the same time an improvement of the acoustic component properties is possible because the resonant frequency of the modified structure is frequently significantly higher compared to the conventionally designed one.

Another important point considering the component development concerns the design of the joint geometry, for joining by EMF, especially considering

- the materials to be connected,
- the load profile which has to be resisted by the joint (tensile and compression forces, respectively, torque load) and
- other demands which have to be fulfilled by the connection (e.g. pressure tightness, optical requirements, etc.).

This aspect does not only include the overall dimensioning of the joining partners, but also the shape, size and alignment of secondary form elements such as grooves or beads as well as conical sections in this area.

FIELDS OF APPLICATION

In principal the EMF technology can be applied in all five groups of production technology (see DIN 8580). However, research at the Fraunhofer IWU focuses on the fields of forming, joining and cutting.

Forming

In case of mere forming tasks usually – however not exclusively – sheet metal components are used. Here, a wide spectrum of drawing depths is possible, starting from values of less than one millimeter in the case of coining or calibrating tasks up to some tens of millimeters. Limitation for sheet metal forming and expansion processes are usually caused by material failure more precisely necking or cracking of the part. In case of compression the formation of wrinkles is usually the limiting effect. The reason for this is that due to the high velocities only very limited material flow is possible from the adjacent areas into the forming zone. Accordingly, the material flow comes from the thickness of the workpiece so that an increase of the surface – as it occurs in case of expansion and sheet forming process – is compensated by thickness reduction and vice versa.

The technology of EMF as an individual process is predestinated for forming small- to medium-sized components. For larger ones, such as body panels for the automotive industry, the technology can be applied advantageously in combination with conventional forming procedures, e.g. deep drawing in order to shape local details such as door handle or license plate cavities.

In order to meet the demand for the economic production of a steadily rising variant diversity and with special interest in an economic production of individualized products under certain conditions multiple similar part geometries can be produced with one and the same set of tools by using the mentioned process integration. For realizing different details, exchangeable tool segments can be inserted into the die.



Due to the contact-free force application, the applied inductor is associated less strictly to the part geometry, compared to conventional forming tools. Provided that part geometries and especially the dimensions of the cavity that is to be formed are similar, the coil need not be exchanged. For shaping defined geometries different strategies were tested at the Fraunhofer IWU. Thereby, forming operations with single as well as multiple subsequent discharges were considered.

Joining by EMF

By means of EMF, similar as well as dissimilar material combinations can be connected to each other. Thereby, the joining mechanism can be

- interference-fit, based on an elastic-plastic bracing,
- form-fit, based on the formation of undercuts and even
- metallic bonding by cold welding.

Even though joining of profiles is the major field of application in EMF, the interest in electromagnetic welding of sheets is steadily increasing. Independent of the geometry of the semi-finished parts, an important precondition for the joining by EMF is, that the joining partner that is to be deformed, should be of preferably high electrical conductivity. In case of joining of profiles, this is frequently the outer component.

The Fraunhofer IWU consults on the most appropriate joining mechanisms for specific applications depending on the properties of the semi-finished part, on the one hand, and the demands to be made on the connection, on the other hand. For instance, a metal to non-metal connection can be realized as an interference-fit or as a form-fit, but not as a metallically bonded joint. Interference-fit connections are especially suitable for materials with relatively low formability, because the required deformations are comparably low. However, the necessary cleaning effort is higher and high joint strengths can frequently be achieved by longer connections only. Via an appropriate design of the secondary form elements in the joining area, form-fit connections can be adapted especially well

to the specific load case. However, similar to interference-fit joints a pressure tight connection can often be guaranteed only if an additional sealing element is applied. Metallically bonded joints are distinguished due to their excellent strength and tightness, but require higher energy and the mechanism is not applicable for any desirable material combination.

Depending on the joining mechanism, the process parameters and the connection area have to be designed. With regard to this aspect, the Fraunhofer IWU has suitable numerical methods and tools as well as the according experimental equipment for verification purposes at its disposal.

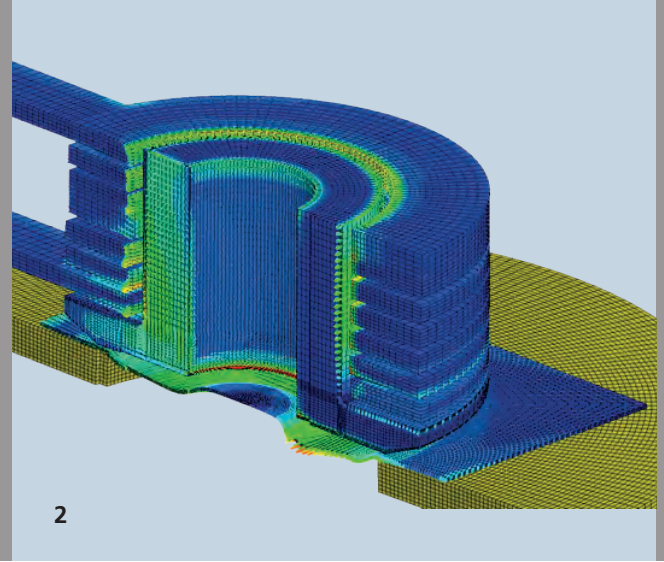
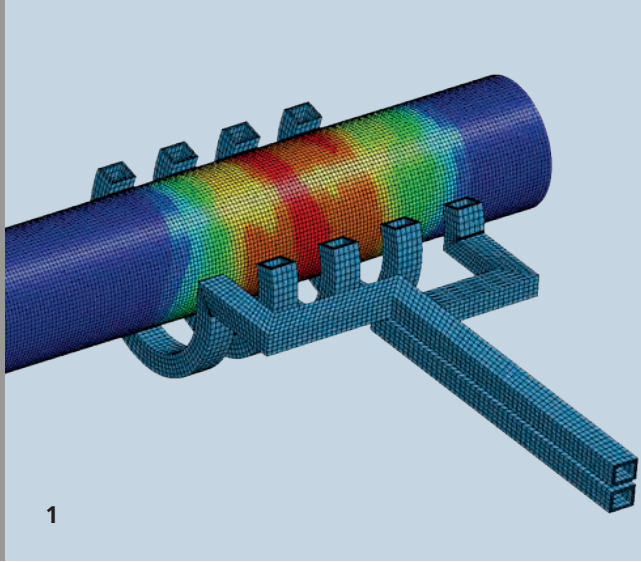
Cutting by EMF

In contrast to conventional cutting processes, in electromagnetic cutting the workpiece is not sheared between two mechanical tools. In fact, one half of the conventional cutting tool is replaced by the inductor. During the process, parts of the workpiece are accelerated, so that initially a deformation takes place and finally – as a consequence of the interaction with the remaining half of the cutting tool – the desired separation of material results. Due to the specific process, the cutting edge usually features a relatively large draw-in at the workpiece surface facing the inductor, but no significant burr or flaking.

Depending on the considered application, it is possible to realize multiple cut-outs within one and the same discharging process and even in combination with a simultaneous shaping of the component. The qualitative and quantitative determination of process limits and interactions between adjacent cut-outs are subject of current research at the Fraunhofer IWU.

1 *EMF-joint aluminum-glass fiber connection*

2 *EMF-joint multi material connections including components made of aluminum alloys, coil fiber and copper alloys*



NUMERICAL SIMULATION

As a consequence of the strong interactions between the electrical and the mechanical field variables, the best method for calculating electromagnetic forming operations is by using a three-dimensional coupled electromagnetic and structural-mechanical simulation. Ideally, this takes the parameters of the pulsed power generator into account via an integrated analysis of the electrical circuit.

For this purpose, a suitable special-purpose simulation tool (LS-DYNA 980 beta solver) is available at the Fraunhofer IWU for scientific investigations. However, in case of larger models, calculation times are relatively long. As a consequence, this tool is only of limited suitability for carrying out comprehensive parameter studies within the frame of tool- and process designs. For that reason, one focus of the research work at Fraunhofer IWU in the field of numerical simulation of EMF-technologies is the development of simplified simulation strategies. These include model simplifications as well as decoupled methods for calculating the electromagnetic and structural problems. By means of these approaches a basic design of tool and process is done. Within the subsequent more detailed design, more accurate FE-analyses are carried out using the above mentioned simulation tool for calculating chosen examples.

In this context, at Fraunhofer IWU it is also possible to model the EMF-process as part of a process combination or process chain. Thus, within the frame of dimensioning a joining operation, at first the formation of a form-fit connection was calculated with the help of the coupled simulation. Subsequently, taking into consideration the influence of the electromagnetic joining step on the material properties, the deformation of the joint resulting from a torsion load was simulated up to the final destruction of the connection. In the broader sense of a process chain simulation, this deformation under load can be interpreted as a subsequent forming operation.

The deviation of experimentally and numerically determined data with regard to the transferable torque load was less than 8 percent in these investigations.

With regard to the dimensioning of metallically bonded joints, the simulation can be used for determining the collision parameters and here especially the impacting velocity and the contact pressure. Then, the evaluation of these parameters with regard to the suitability for the formation of a metallic bonding can be done considering expert knowledge or literature values. The simulation of cutting operations can be carried out directly based on the coupled simulation with the special-purpose simulation tool by LS-Dyna via an evaluation of the occurring strains and the typical failure criteria, respectively. As an alternative, the cutting process can be calculated as a decoupled step using conventional simulation tools. In this case, the acting forces determined via the coupled simulation serve as input data.

The thermal field variables and here especially the temperature distribution can also be calculated in a coupled way together with the electromagnetic and structural mechanical simulation by using the thermal solver in LS-DYNA. Due to the coupling of the electromagnetic and the thermal solver, also a simulation of the target-oriented inductive heating of workpieces is possible. This can be exploited for an optimum dimensioning of the induction coils as well as the determination of the necessary heating time and temperature distribution due to eddy currents. These investigations are also suitable in relation to other applications as e.g. press-hardening processes or hot metal gas forming. Both techniques are also research foci of the Fraunhofer IWU in the field of sheet metal forming.

PROCESS ADVANTAGES AND RECOMMENDATION FOR PRAXIS

Due to the contact-free force application even sensitive, structured or coated surfaces can be processed, as long as the coating tolerates the required strains. Mechanical wear of the tools due to tribology does not occur and the application of lubrication is not required. Thus, the process is economically friendly and cleaning effort during production is significantly reduced.

Under the process-specific forming conditions and especially the high strain rates and velocities, significantly higher deformations compared to conventional processes can be achieved for numerous materials. Moreover, springback is reduced significantly.

The process can also be carried out under special conditions as e.g. in a vacuum, a clean room or radioactive environment by using a remote control.

For the pressure application no working medium is required, so that even workpieces without closed surface as e.g. perforated sheets can be electromagnetically formed, provided that the induced eddy-currents can form a closed current path. In case of electromagnetic compression and expansion, this requires a closed cross section geometry.

For materials of high electrical conductivity as e.g. copper- or aluminum alloys, high process efficiency can be achieved. In case of a sophisticated adaptation of the pulsed power generator, inductor and process parameters, the ratio of forming energy and capacitor charging energy can be in the range of 25 percent. In case of materials of lower electrical conductivity, a so-called driver – i.e. an additional high conductive component – can be inserted in-between inductor (and fieldshaper, respectively) and workpiece in order to improve process efficiency or enable the process at all.

High process efficiency further requires small gap-widths between the inductor, the fieldshaper and the workpiece. Desirable are distances of one millimeter or less in the initial setup. Initial distances of up to three millimeters should not be exceeded.

The process can be applied for sheet thicknesses of some tenths of a millimeter up to a few millimeters. In case of high stiffness and strength, the required energy rises. In case of extremely thin sheets or profile wall-thicknesses, sometimes no efficient shielding of the magnetic field and consequently no pressure application is possible. As in case of low conductive workpiece materials, the application of a driver might be necessary, here. However, in case of extremely thick or thin workpieces as well as in case of large electromagnetic forming operations, the feasibility has to be investigated.

1 *Temperature distribution determined via finite element simulation of the inductive heating process*

2 *Current density distribution determined via finite element simulation of the electromagnetic forming process*

3 *Aluminum-sheet cut via electromagnetic forming*

Publishing Notes

Fraunhofer Institute for
Machine Tools and Forming Technology IWU
Reichenhainer Strasse 88
09126 Chemnitz, Germany

Phone +49 371 5397-0
Fax +49 371 5397-1404
info@iwu.fraunhofer.de
www.iwu.fraunhofer.de

Director

Scientific Field Forming Technology and Joining

Prof. Dr.-Ing. Dirk Landgrebe
Phone +49 371 5397-1420
dirk.landgrebe@iwu.fraunhofer.de

Group Electromagnetic Forming

Dr.-Ing. Verena Psyk
Phone +49 371 5397-1731
Fax +49 371 5397-1298
verena.psyk@iwu.fraunhofer.de