DR. RUPA DASGUPTA
Sr. Principal Scientist, CSIR - AMPRI

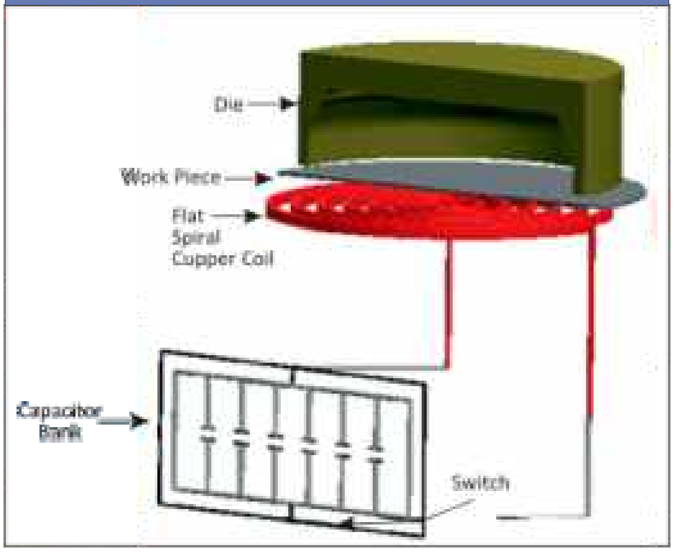
AMPRI Bhopal is involved in research work related to Electromagnetic Forming (EMF) and its main focus is to develop this technology for industrial application. Study on material deformation at high strain rate and computer simulation of the process was envisaged at first instances.

Electromagnetic Forming and its Activities at CSIR-AMPRI

Electromagnetic Forming (EMF) is a high velocity/strain rate forming process, which utilizes pulsed magnetic force to deform metallic workpiece. Essential components of an EMF system include a conductive coil, called the work coil, a charging and control system, and energy storage capacitors. A typical setup is shown schematically Figure 1

The capacitors are charged from the line voltage supply, and then the entire circuit is isolated from the power source. When the forming circuit switch is closed, charge stored in the capacitors flows as a current through the work coil. The current creates a strong magnetic field between the coil

Figure 1 : Basic Element EMF Process Set Up



and the workpiece. This field in turn induces a current in the conductive workpiece and sets up an opposing magnetic field. The interaction between the two magnetic fields creates a magnetic pressure pulse strong enough to force the workpiece into a new shape.

The shape created depends on the type and location of the work coil. A spiral coil around the outside of a tubular workpiece will deform it inward [Figure 2(a)]. This is the most common application for EMF since it can be used to attach and assemble a wide variety of components and parts. A spiral helical coil inside a tubular workpiece will bulge or flange it outward [Fig. 2(b)]. A flat coil is used most frequently for forming flat metal sheets [Fig. 2(c)]

In addition to forming, the electromagnetic process can be used for joining, shaping encapsulating and welding. There are a number of advantages of the electromagnetic forming process over conventional forming process and they are:

- Lower energy consumption as compared with competing technologies
- High reproducibility and productivity.
- High formability of material: It is more effective than conventional stamping. There is increased formability in critical regions.
- No wrinkling and less spring back (of special advantage for Al and Mg)
- Forming can be performed at room temperature.
- Non-contact Type : There is generally no need for lubricants, so cleaning and post finishing are rarely necessary.
- Flexibility : A wide range of shapes can be produced, and the systems are smaller and more flexible than hydraulic presses of comparable capacity.
- Very Fast : Energy release to the work coil takes only microseconds and capacitors recharge in a few Seconds.
- Easily Automable : High production rates are possible.
- Clean Room Compatible : Components made in a clean environment can be sealed in a plastic bag and can be formed with the bag.

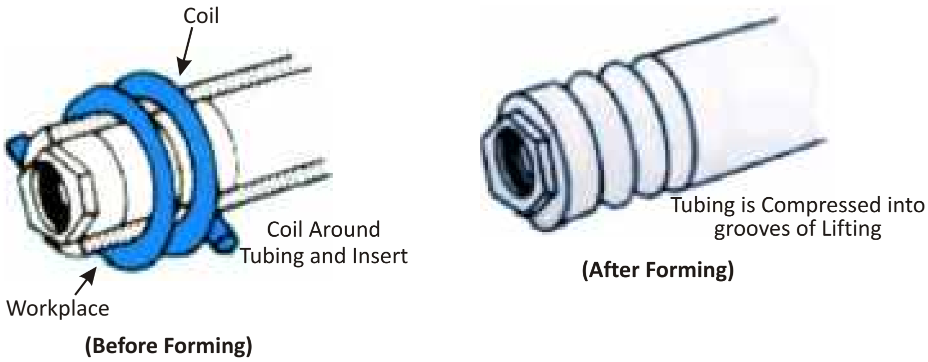


Figure 2(a) : Compression Coil for Compression Type Emf Operation [Courtesy: (2)]

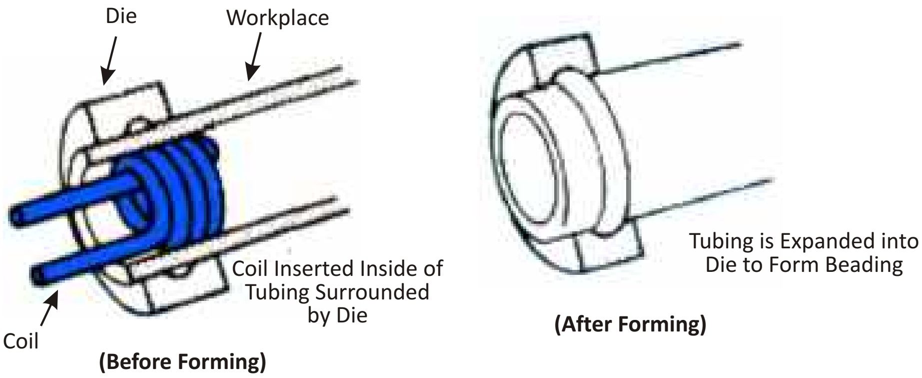


Figure 2(b) : Expansion Coil for Expansion Type Emf Operation [Courtesy: (2)]

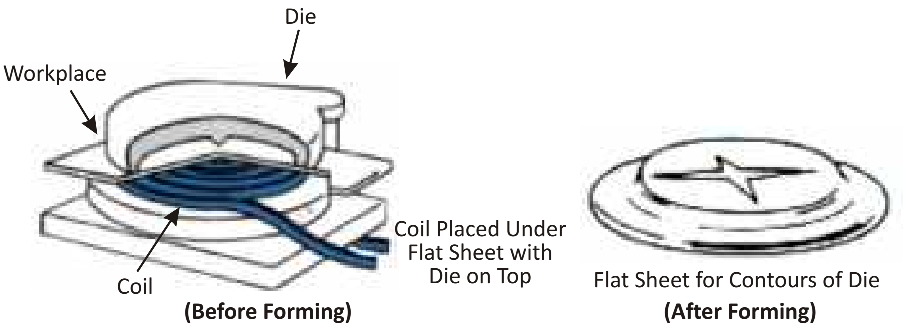


Figure 2(c) : Flat Spiral Coil for Sheet Metal Forming Type EMF Operation. [Courtesy: (2)]

- Cost Effective Process : The whole process is performed in lesser steps with simple tooling.
- Joining of Dis-similar Metals : The process joins metals to other metals or nonmetals without any HEZ
- Causes Minimal Tool Wear : Only the coils need to be replaced occasionally.
- Eliminates the need for welding (especially in aluminum alloys).
- Eliminates quality problems by improving forming quality of sheet.
- Higher strains without the failure of the material.
- High uniformity and reliability with less prone to operator errors.

However, there are some limitations and they include:

- Work piece must be electrically conductive and preferably have a high Electrical conductivity.
- Process suitable for only thinner materials.
- Minimum inside tube diameter is about 50 mm for expansion applications.
- Coils/ Actuators are relatively expensive.
- High-resistance work pieces cannot be formed. It requires high conductive drivers, which can be used

only once and may have to be removed.

- Number of equipment vendors is very limited.
- Safety considerations are high due to the high voltages operations.
- Large components cannot be formed mainly due to problems in design of very large coils and its tooling.
- Life of the coil is limited.

Work Carried out at CSIR-AMPRI, Bhopal

AMPRI Bhopal is involved in research work related to Electromagnetic Forming (EMF) and its main focus is to develop this technology for industrial application. Study on material deformation at high strain rate and computer simulation of the process was envisaged at first instances. The coil/actuator design is also an important task for effective forming. Some preliminary studies on above aspects were carried out.

Finite Element simulation of the EMF process involves coupling of three physics: Electromagnetics, Structural and Thermal. There is no readily available FE sofwares that can couple these physics easily. At CSIR-AMPRI, such problems were simulated using commercial FE sofwares. Such problem can be solved by two coupling strategy namely Loose coupling and Sequential coupling. In loose coupling, the Lorentz force is calculated in the electromagnetic model and it is transferred manually as an input load to the structural model for the simulation of the workpiece deformation behavior. It is less accurate than the sequential coupling but it is most flexible because it leads to the simple model. This type of coupling is used to estimate the order of magnitude of many parameters of the EMF. Sometimes only electromagnetic model is solved to estimate electromagnetic process parameters to design the EMF equipment or coil. In Sequential coupling, during each defined time step the Lorentz forces developed on the work piece are first calculated from electromagnetic model and then automatically transferred to structural model. This way the deformation of the workpiece is calculated and the electromagnetic model is up-dated. This loop of automatic switching from Electromagnetic model to structural model continues till final time step is reached. A similar approach has been taken up in LSDYNA. In LSDYNA, once the EM field has been computed, the Lorentz force

References :

1. E.J. Bruno,"High-Velocity forming of Metals", ASTME, 1968
2. TechCommentry: Electroforming, Vol.3, No.5, 1986, Published by EPRI Center for Materials Fabrication, USA
3. Following websites:
   - http://natt.pnl.gov/tech/electro_alum.pdf, Aug 2008
   - http:// www.iap.com/, Aug 2008
   - http://www.mse.eng.ohio-state.edu.com, Dec 2011
   - http://www.magnepress.com, July 2008
   - http://epaper.kek.jp, July 2008
   - http://www.magneform.com, Aug 2008
   - http://www.thefabricator.com, Aug 2008
   - http://www.va.gov, July 2008
   - http://en.wikipedia.org, July 2008
   - http://researchnews.osu.edu/archive/metalfrm.htm, Aug 2008
4. G.S.Daehn, *Electromagnetically Assisted Stamping-A vision of a future for metal Forming*, http://www.mse.eng.ohio-state.edu, Dec 2011
5. http://www.osu.edu/hyperplasticity, Dec 2011
6. Seth Mala, Vohnout V.J. and Daehn G.S., *Formability of steel sheet in high velocity impact*, J. of Materials Processing Technology, Vol.168, pp. 390-400, 2005
7. L. V. Belyy, S. M. Fertik and L. T. Khimenko, *Electromagnetic Metal Forming Handbook, (A Translation of the Russian Book: Sprvochnik Po Magnitno-impul' Snoy Obrabotke Metallov)*, Translated by M. M. Altynova and Glenn S. Daehn, Columbus, OH, 1996
8. A. G. Mamalis, D. E. Manolakos1, A. G. Kladas, and A. K. Koumoutsos, *Electromagnetic Forming Tools and Processing Conditions: Numerical Simulation*, Materials and Manufacturing Processes, 21: 411–423, 2006
9. P. L'Eplattenier, G. Cook, C. Ashcraft, *Introduction of an electromagnetism module in LS-DYNA for Coupled Mechanical Thermal Electromagnetic Simulations*, 3rd International Conference on High Speed Forming – 2008.
10. Pierre L'Eplattenier, Grant Cook, Cleve Ashcraft, Mike Burger, Art Shapiro, Glenn Daehn, Mala Seth, *Introduction of an Electromagnetism Module in LS-DYNA for Coupled Mechanical-Thermal-Electromagnetic Simulations*, 9th International LS-DYNA Users Conference

(This article has been compiled in Asst. with Meraj Ahmed & Amol K. Jha, Scientists, CSIR-AMPRI)

❍❍❍