Electromagnetic forming

Electromagnetic forming (EM forming or magneforming) is a type of high velocity, cold forming process for electrically conductive metals, most commonly copper and aluminum. The work piece is reshaped by high intensity pulsed magnetic fields that induce a current in the work piece and a corresponding repulsive magnetic field, rapidly repelling portions of the work piece. The work piece can be reshaped without any contact from a tool, although in some instances the piece may be pressed against a die or former. The technique is sometimes called high velocity forming.

A rapidly changing magnetic field induces a circulating electrical current within a nearby conductor through electromagnetic induction. The induced current creates a corresponding magnetic field around the conductor. Because of Lenz's Law, the magnetic fields created within the conductor and work coil strongly repel each other.

When the switch is closed, electrical energy stored in the capacitor bank (left) is discharged through the forming coil producing a rapidly changing magnetic field which induces a current to flow in the metallic work piece (pink). The current flowing the work piece produces a corresponding opposite magnetic field which rapidly repels the work piece from the forming coil, reshaping the work piece - in this case, compressing the diameter of the cylindrical tube. The reciprocal forces acting against the forming coil are resisted by the 'supportive coil casing'.

In practice the metal work piece to be fabricated is placed in proximity to a heavily constructed coil of wire (called the work coil). A huge pulse of current is forced through the work coil by rapidly discharging a high voltage capacitor bank using an ignitron or a spark gap as a switch. This creates a rapidly oscillating, ultrastrong electromagnetic field around the work coil.

The high work coil current (typically tens or hundreds of thousands of amperes) creates ultrastrong magnetic forces that easily overcome the yield strength of the metal work piece, causing permanent deformation. The metal forming process occurs extremely quickly (typically tens of microseconds) and, because of the large forces, portions of the work piece undergo high acceleration reaching velocities of up to 300 m/s.
Electromagnetic forming is the only high velocity forming technique to gain significant acceptance in commercial metal working. The electromagnetic forming technique has been in use commercially for the last 30 years. Mostly, it has been used for joining and assembly of concentric parts. The minimal springback inherent in all high velocity forming processes provides high-quality joints.

Fig.2 -- Schematic illustration of electromagnetic forming showing a) solenoidal and b) flat forming coils.

One of the most common applications of electromagnetic forming is the compression crimp sealing and assembly of axi-symmetric components such as automotive oil filter canisters. As the name implies, in this technique, electromagnetic forces are used to form the material. A current pulse from a capacitor bank is passed through a coil that is placed in close proximity to a work piece. The current pulse causes a high-magnetic field around the coil. This field induces an eddy current in the work piece and an associated secondary magnetic field. The two fields are repulsive and the force of magnetic repulsion causes deformation of the work piece.
The designed shape and electrical characteristics of the coil depend on the work piece. Coils can be developed for most practical forming geometries including forming of flat sheets. Fig. 2 is a schematic illustration of electromagnetic forming showing a) solenoidal and b) flat forming coils.

The nature of the electromagnetic forming process makes it highly suitable for automation. Results obtained are very repeatable because energy discharge characteristics are controlled essentially by the non-changing electrical parameters of the system and precise control of capacitor bank charge voltage. The fundamental physical characteristic of this technique is that the deformation forces initially are only magnetic body forces generated within the material by eddy currents induced by the drive coils. Surface pressures only occur upon contact with the form tool. This can provide deformation capabilities that are difficult to obtain with other forming methods.

Although there are no fundamental limitations to the size of parts that can be made by electromagnetic forming, larger parts require more energy, which translates into larger capacitor banks and higher initial capital expenditure. As a result, hybrid forming processes are being considered, where electromagnetic methods would be used only to form areas of the workpiece that can not be formed conventionally.

In principle, both electromagnetic and electrohydraulic forming can be used in such a hybrid process. A matched tool set with electromagnetic coils built into sharp corners and other difficult-to-form contours is one way of forming these parts. Matched tools would be used to form sections of the work piece that can be formed easily at low velocities using mechanical energy from the press.

This semi-formed work piece then would be subjected to high-velocity forming with electromagnetic coils used to complete the forming operation. Similarly, a quasi-static, fluid-pressure process, with an electrical discharge in the fluid at the end of the pressure cycle to form sharp corners and bends, could represent another hybrid method for making difficult parts, integrated into the tool assembly. However, for many simpler parts, electromagnetic forming can be used right away, metals producers to automobile and aerospace companies. Under the auspices of this consortium, a research program is being conducted to understand the fundamentals of material behavior during high-rate forming while concurrently developing practical forming technology. Even though more aspects of material behavior are beginning to be understood and workable processes are being developed, further research is essential.

**Applications**

The forming process is most often used to shrink or expand cylindrical tubing, but it can also form sheet metal by repelling the work piece onto a shaped die at a high velocity. Since the forming operation involves high acceleration and deceleration, mass of the work piece plays a critical role during the forming process. The process works best with good electrical conductors such as copper or aluminum, but it can be adapted to work with poorer conductors such as steel.
Electromagnetic forming has a number of advantages and disadvantages compared to conventional mechanical forming techniques.

Some of the advantages are:

- Improved formability (the amount of stretch available without tearing)
- Wrinkling can be greatly suppressed
- Forming can be combine with joining and assembling with dissimilar components including glass, plastic, composites and other metals.
- Close tolerances are possible as springback can be significantly reduced.
- Single sided dies are sufficient which can reduce tooling costs
- Lubricants are reduced or are unnecessary, so forming can be used in clean room conditions
- Mechanical contact with the workpiece is not required, this avoids surface contamination and tooling marks. As a result, a surface finish can be applied to the workpiece before forming.

The principle disadvantages are:

- Non conductive materials cannot be formed directly, but can be formed using a conductive drive plate
- The high voltages and currents involved require careful safety considerations
- Large sheet metal components cannot readily be formed, due to current limitations on the design of very large coils

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