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Optimization of tool coils for electro-magnetic forming application

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Abstract

The goal of this review article is to provide comprehensive discussion about the coil limitations and developments. The advancement of the technology in this field plays a vital role in the quality that can be achieved for poor formability alloys. The influence of essential parameters that governs the use of coils in different applications is further explained. Research revealed that the most influential parameter is the coil design, and hence, so many of the currently available designs are discussed alongside their applications and effect on the final products. Furthermore, this study addresses the different approaches, recommended by prominent researchers, to improve the coils performance and the quality of the finished products.

Keywords: optimization, tool coils, electro-magnetic forming application

INTRODUCTION

Due to the environmental concerns, the need for lightweight components is increasing especially for automotive and aviation & aerospace industry [1-3]. That means high strength aluminum and processing techniques need to be introduced. The reason is that aluminum alloy has low formability and that negatively affects its industrial applications as shown by [4]. Electromagnetic forming has found its way to automotive and aviation & aerospace industries because it can be a good process to form aluminum alloy despite its poor formability [5].

Electromagnetic forming is a high-speed forming technique to achieve the required finished product by the electromagnetic body force which is generated by pulsed varying magnetic field as illustrated in [6]. If EM forming is compared with conventional processes it has two main advantages. Firstly, it can achieve much higher formability up to 10 times as shown in [7]. Secondly, because there is no contact between the tool and the workpiece, higher surface quality can be achieved as illustrated in [8].

Psyk et al. [9] showed that electromagnetic forming can widen the process window of the low formability alloys at room temperature, improve spring back control, and decrease wrinkling. Utilizing Lorentz forces, EM forming can form tubes and sheet metals to achieve finished products with different shapes and length ranges as shown in [10]. It was also indicated in this paper that a workpiece with 1 m scale can be shaped as well as local deformations can be produced.

In sum, EM forming is generally used to form small parts or the local features of the large sheets. But all the promises of the EM forming are challenged mostly by coil ability to produce magnetic field and provide the energy needed to the workpiece. This essay provides a review about the developments occurred in the coil designs as well as the efforts made to improve the process and the resulting product quality. The second section will talk about the need for coils optimization and give a brief about the problems happening with the coil and the process limits. The third and fourth sections will provide some of the designs which are typically used and the designs which were introduced recently to meet certain applications requirements.

NEED FOR OPTIMIZATION OF THE COILS FOR EM FORMING:

Psyk et al. [9] defined the most important properties needed in the coils, which are having high energy efficiency, high mechanical strength, and providing the adequate frequency of the current. Werdelmann et al. [11] showed that only a small part of the discharge energy is transferred to the workpiece as an EM force and more than a half heats the coil, so increasing the charge energy amounts to coil damage and decreasing lifetime. That makes it difficult to design a coil that can process large and thick-walled sheet metals. Cao et al.

[12] showed that a conscious effort should be made in the area of decreasing the rising temperature of coils in electromagnetic forming, and to do so new designs and types should be introduced to enhance electromagnetic force distribution.

The strength and durability are covery important because the coil should overcome the reaction forces resulting from the deformation as well as the forces between the turns. Bearing in mind that the closer the coil the better workpiece deformation, but higher the reaction force. It is also important to state that during the EM forming process, the gap width is varying, so different load cases and values occurs. Therefore, this must be considered during the design of the coils as discussed in [9].

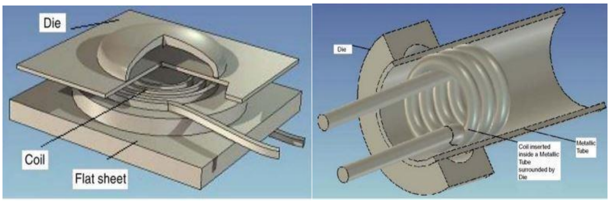
In designing the coils, two ideas were proposed. Firstly, is to design a coil that is durable for multiple pulses which not many efforts were made in this direction. Second idea is to design a disposable coil and an example of that is shown in [13].

The need for optimization of coils deeply depends on the application. For example, the coils for constant diameter tube are different from that of varying diameter tube. Also the currently available coils cannot shape the large sheets like the small sheets without using special techniques. This will be discussed in the next sections.

POSSIBLE COIL DESIGNS IN EM FORMING FOR VARIOUS APPLICATIONS:

In this section, many kinds of coil designs will be discussed with related applications as well as the effect of the coil design on the EM forming process and the formed parts.

Psyk et al [9] showed many kinds of coil designs that can be used in metal forming. In this manner, the helical coil mostly used in the area of tube expansion and compression. Spiral coil which is a coil that has multi-layers and single turn is usually used to shape sheet metals which are symmetric in the radial direction. But also many kinds of coil geometries were cited by [9] in sheet metal forming like a trident coil geometry, ellipsoidal, super ellipsoidal geometries, and more. It was also illustrated in the review that the flat coil which is usually the term associated with the EM forming can be used in bulk forming too. To do this, coil surface should be modified to the shape of the workpiece to achieve a small gap between the coil and the workpiece.



Fig(1): Flat coil used to form sheet metal (left) and a spiral coil used for tube expansion (Okoye et al. [14])

Oliveira et al. [15] developed a double spiral coil that can form a workpiece resembles a box which single spiral coils cannot produce because of the "dead spot" happened at the center of winding in the single spiral coils. Ahmed et al. [16] used FEM to design a coil with different cross sections and spacing to produce a larger maximum force and a uniform electromagnetic force distribution. And also the maximum pressure goes more to the center of the workpiece to achieve better deformation behaviour.

In the same manner and in an attempt to make a design to avoid the poor dimensional accuracy of variable-diameter tubes in EM forming with constant spacing coils, Li et al. [17] suggested the idea of using gradient electromagnetic forming (GAMF). In the study it was shown an analytical formula correlated the spacing in the coils and the electromagnetic force produced.

By that, the forces can be controlled in such a way to produce tubes with varying diameters across its axis. Additionally, it was illustrated the relation between the coil design in term of spacing and the die-fitting gap. This method showed high dimensional accuracy for varying diameters tubes.

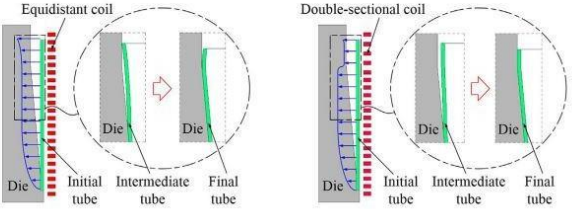


Fig (2): Forming process of variable diameter tubes use constant spacing coil (left) and double-sectional coil with GAMF process (right) (from [14])

Qiu et al. [18] analysed the deformation in the tube expansion process by a concave coil using Finite element method. Compared to the cylindrical coil it is found that the concave coil has more homogenous deformation of the tube in the axial direction. It is found that there are two maximum electromagnetic force points as well as the deformation in the mid-point is decreased.

Luo et al. [19] suggested the idea of using multi-layer coil and analyses its structure to increase the skin depth on the workpiece due to the increase of equivalent inductance which leads to raise the energy efficiency. And as per their results, this coil can be better fit in forming large and thick-walled components.

Their studies also showed that because of the share of each layer in a multi-layer coil, the acting pressure on the coils can be better controlled. It is also shown in the study that the energy efficiency increases with the reduction of coil distance because that improves the magnetic field on the sheet. Closely wound coils also showed higher energy efficiency.

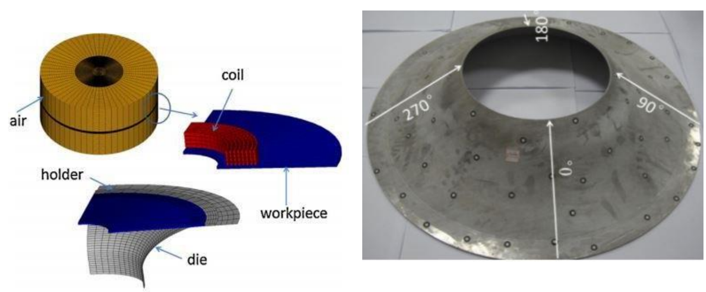


Fig (3): Electromagnetic forming elements with multi-layer coil (left) and the final component after two-timing electromagnetic forming (from [19])

The conventional EM tube forming uses a spiral coil to expand the tubes, but that results in a reduced strength. A new design was introduced to mitigate the risk of losing the strength by adding another coil in the axial direction to provide an axial magnetic field. The radial magnetic field leads to the expansion of the tube, while the axial magnetic field amounts to compression of the tube. This technique was explained in [18] as shown in Fig (4)

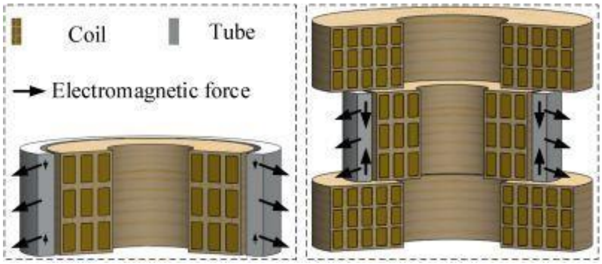


Fig (4): Coil system of the conventional EM forming process (left), and EM forming process with axial compression (right)

OTHER POSSIBILITIES OF COIL OPTIMIZATION FOR EM FORMING:

Because of the limitation of the process and coil design in forming of large-scale sheets, new technique called EM incremental forming merged electromagnetic forming with digital control was introduced to deform large scale sheets.

The idea is to form locally a part of the large sheet, and by the use of the computer control the coil can be moved to form the entire sheet.

In [6] the researchers designed an electromagnetic forming system which included the design of inductance, strength, and capacity coefficient. The coil used here is multi-layer multi-turn with reinforcement. The results showed that this design provided higher electromagnetic force compared to multi-layer single-turn coil without reinforcement.

Lai et al. [10] thought in another way and wanted to explain the relation between electromagnetic and mechanical forces in term of coil polarity when multi-coil EM forming technique is used. The polarity has an effect on the current flowing in the coils which has effects on magnetic field, Lorentz force and the resulting deformation. This study used both numerical simulations and experiments on a dual-coil system. It is found that the polarity has an effect on the shaping of the workpiece, and the same polarity for both coils has higher energy efficiency, larger forming depth, a decreased thinning and smoother profile.

It was also shown that electromagnetic interaction between the two coils beside the interaction between the coils and the workpiece has an effect on the currents flowing through the coils and the induced current on the workpiece which influences the workpiece deformation. Su et al. [5] thought in the direction Electromagnetic calibration which was proven to have high dimensional accuracy components.

Two-step EM forming method including forming and calibration was proposed to produce oblique holes. The key process parameters in this study was investigated by experiments, while the deformation behaviour was analyzed by simulations. By this technique high dimensional accuracy of local features and a decreased die-fitting gap were achieved. The extension of the deformation can also be observed by utilizing optical methods such as scanning electron microscope (SEM) and X-ray computed tomography [20-22].

Another technique is also introduced to increase the deformation depth in sheets by the so-called space-time-controlled multi-Stage pulsed magnetic field forming. The design is to use two coils to produce electromagnetic forces in the axial and radial directions. This method showed higher formability compared to the conventional EM forming with single coil as illustrated in [18].

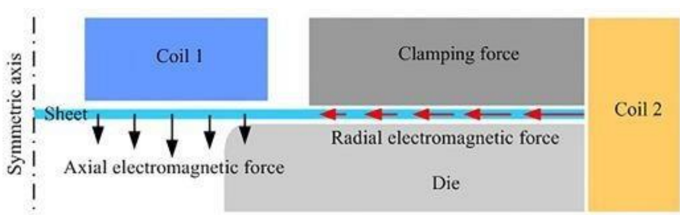


Fig (5): Schematic drawing of a system space-time-controlled multi-Stage pulsed magnetic field forming

Okoye et al. [14] used a technique named it electromagnetic-assisted stamping. The benefits of the EM forming are used to improve the product quality and dimensional accuracy especially with corner filling. The idea is to put the EM coils in the punch of the stamping process.

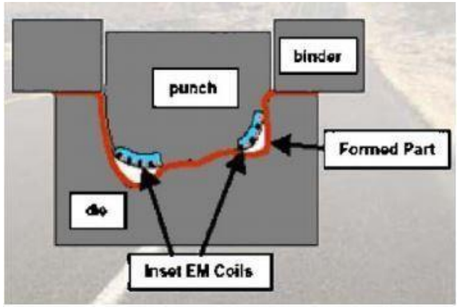


Fig (6): Electromagnetic stamping equipment

Lai et al. [23] designed an EM forming system that uses dual coil to do a deep drawing. This system has shown with the experiment that the forming depth can be increased more than the double compared to conventional deep drawing using single-coil EM forming process. It is also illustrated in the study the tearing effect which happens to due to the increase of the pressure can be significantly decreased by introducing a radial force by the use of the dual-coil system.

Zhang et al. [24] introduced a new system design and made a numerical simulation to use three coils to increase the deformation depth of tubes which is limited in the single coil system. Two coils were placed in the two ends of the tube to produce an axial electromagnetic force.

SUMMARY AND CONCLUSION

In this review article, the coil limitations and developments are investigated. The technology seems to be very promising due to the quality that can be achieved for poor formability alloys. It is addressed here the important properties needed in the coils to meet different applications requirements. The most influencing parameter is the coil design, so many of the currently available designs are discussed with their applications and the effect on the finished products. Additionally, many ideas proposed by the researchers about improving the performance of the process which focused on the coil performance are also illustrated.

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