Applications of Electromagnetic Forming Technology at the Wuhan National High Magnetic Field Center

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Abstract

The research of the electromagnetic forming (EMF) technology at the Wuhan National High Magnetic Field Center (WHMFC) has focused on designing electromagnetic system for generating a more flexible and strong Lorentz forces acting on workpieces, and then expanding the applications of EMF technology to solve current problems in forming large-scale and complex components. In this paper, we will sum up the latest progress of EMF technology at the WHMFC in detail according to recently reported works.

Keywords: Electromagnetic forming, large-scale workpiece, electromagnetic system, Lorentz force

1. Introduction

Electromagnetic forming (EMF) is a high-rate forming technology that reshapes metal workpieces by means of electromagnetic forces (Lorentz forces), which has been demonstrated to be effective in improving formability, reducing springback and wrinkling[1]. Therefore, this technique has been widely applied for forming of both sheet and tube metal parts[2-5]. A common feature of these existing studies is that only a single coil and a single power are typically used, in which the transient magnetic field generated by the coil and induced eddy current in the workpieces are highly coupled. This may result in a poor controllability of electromagnetic force distribution and then could have adverse effects on the forming quality in same cases.

To produce more flexible electromagnetic forces and broaden the applications of EMF, the Space-Time-Controlled Multi-Stage Pulsed Magnetic Field (Stic-Must-PMF) forming technology has been proposed in our previous work[6]. Strong electromagnetic forces can be generated by introducing the nondestructive pulsed high field magnet technology to fabricate tool coils with high strength and long life performance. Meanwhile, the distribution of these forces acting on the workpiece can be well adjusted by using multiple tool coils and several sets of pulsed power systems, in which each coil is energized individually by different power supplies with a precise timing control. To validate the effectiveness of the improved EMF technology, a three-stage forming system with three types of pulsed power supply and a timing control system has been developed at WHMFC, and several studies are carried out that will be introduced in the following sections in detail.

2. Applications of Stic-Must-PMF

2.1 Deep drawing of sheet metal

How to realize deep drawing of sheet metal with a high drawing ratio by use of EMF is interesting and challenging. For conventional single-coil EMF system, the axial Lorentz force is dominant in the forming process and the radial Lorentz force is quite small. In this case, the deformation behavior of a sheet with a drawing ratio of 3.25 almost completely lies on the stretching, which will easily lead to tearing with the increase of the axial Lorentz force and then the maximum drawing depth of sheet metal is limited. To solve this problem, a dual-coil EMF system has been developed in our group, as shown in Fig. 1, in which a radial inward force in the flange region of sheet metal is introduced to enhance the material flow and inhibit the tearing. To realize the magnitude control of axial and radial Lorentz forces, two independent pulsed power systems with capacitor banks are used to energize the two coils. By controlling the discharging voltages of the two power systems, the axial and radial Lorentz forces can be well controlled. Meanwhile, the timing control of the two Lorentz forces can also be realized by using light-activated thyristors in each power system with the aid of independent optical pulse signals. On this basis, experiments for deep drawing of AA1060-H24 with a drawing ratio of 3.25 have been carried out. Results show that the material flow of the flange can be significantly enhanced by increasing the radial Lorentz force and the maximum forming depth without failure has greatly increased from 8.44 mm to 20.28 mm[7], and this value can be further increased to 45 mm through multiple discharges, as shown in Fig. 2. Further, the underlying mechanism of the enhanced deep drawing have been analyzed through both numerical and experimental studies, which can refer to our previous work for details[8].

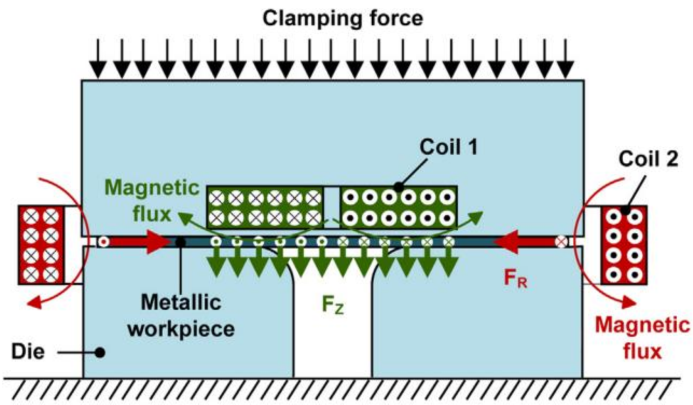

Fig. 1. Schematic diagram of the dual-coil EMF system for deep drawing[8]

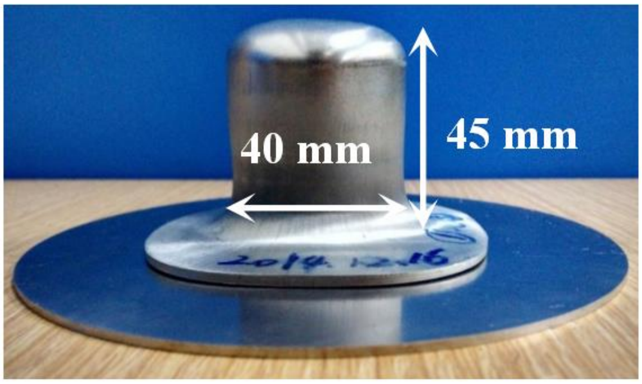

Fig. 2. Photographs of the Original and formed sheets

2.2 Large sheet metal forming

Up to now, most existing studies of EMF technology have focused on the forming of small sheet metal parts (typically less than 800 mm diameter). The main reasons for this issue are: 1) the performance of the conventional EMF system is limited by the strength of the pulsed driving coil. Therefore, the magnetic field strength generated by conventional EMF system cannot be strong enough to improve the forming range and depth which has restricted its extensive application in the large sheet metal forming. 2) the cost of EMF could greatly increase with the increasing of workpiece size. To solve these problems, we have recently developed a new EMF system that can shape large sheet metal parts with a light-weight equipment[9]. As shown in Fig. 3, the system mainly consists of four major sub-systems including die, forming coil, blank holding system and Inertia confinement system. Compared with conventional EMF system, the proposed system has special advantages: 1) all the coils in the system are designed and fabricated based on the theory of high-field pulsed magnets, in which high strength glass fiber has been used to reinforce these coils to ensure their performance life. 2) a pulsed electromagnetic blank holding system has been proposed to replace conventional mechanical ways, in which a high attractive Lorentz force can be generated between the upper and lower coils for blank holding. An obvious advantage of the system is that the generated blank holding force (BHF) can be self-restrained, and therefore no heavy framework is required to constrain the counter force. The design principle of the new blank holding system can refer to our previous work[10]. 3) an inertia confinement (IC) system with the aid of a counter weight has been proposed to confine the upward motion due to the counter force acting on the coil in the forming process, which can effectively simplify the forming equipment that generally complicated and heavy as well as the total cost. The new EMF system has been implemented, and its feasibility on manufacturing ellipsoid-shaped AA5083/AA2219 parts with 1378 mm diameter has been validated in the experiments. As an example, the photograph of the formed workpieces made of AA5083 is shown in Fig. 4, which has a maximum depth of 225 mm and a maximum thinning of 9.48%[10].

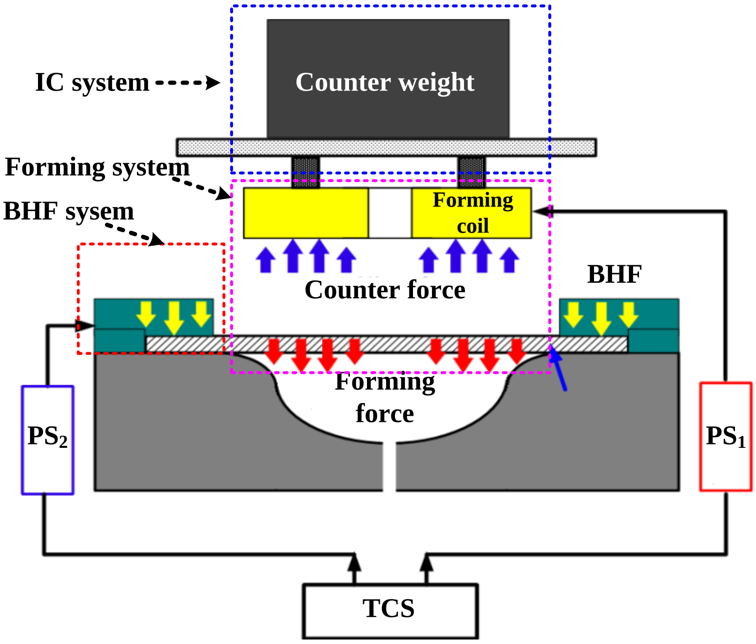

Fig. 3. Schematic diagram of an EMF system for large sheet forming. PS_1, PS_2 and TCS respectively represent 1st power supply, 2nd power supply and timing control system.

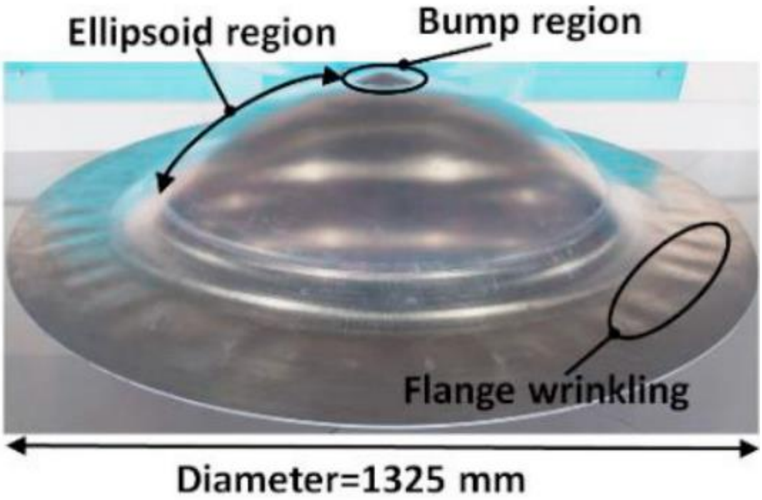

Fig. 4. Photograph of the formed workpiece with an initial diameter of 1378mm[9]

2.4 Electromagnetic attractive forming

As mentioned in the introduction, the electromagnetic force distribution in the workpiece is hard to alter in the conventional EMF systems with a single coil and a single power supply system. Therefore, most research efforts focused on the development of EMF with repulsive forces between the EMF coil and conductive workpiece. Actually, in addition to the conventional repulsive forces, EMF process can be realized by use of attractive forces and this could contribute to more wide applications such as external dent repair, dis-assembly of press-fit joints and forming of small tubes. Nevertheless, compared with the conventional repulsive process, it's a challenging issue to generate efficient attractive magnetic forces between the coil and workpiece. To realize the attractive forming process, an electromagnetic discharge system with two sets of power supply and a timing control system in Fig. 5(a) was designed, implemented and tested in our previous work[11]. The two capacitor banks in the discharge system are electrically connected to a single tool coil with opposite electrical charges, and light-activated thyristors are applied to sequentially trigger the two discharge systems with the aid of a timing control system. By use of the discharge system, the dual-frequency coil current in Fig. 5(b) can be obtained, which has been demonstrated to be effective for realizing the attractive deformation of an AA1060-O aluminum alloy sheet with a thickness of 1 mm. The presented results could be helpful in widening the applications of EMF technology.

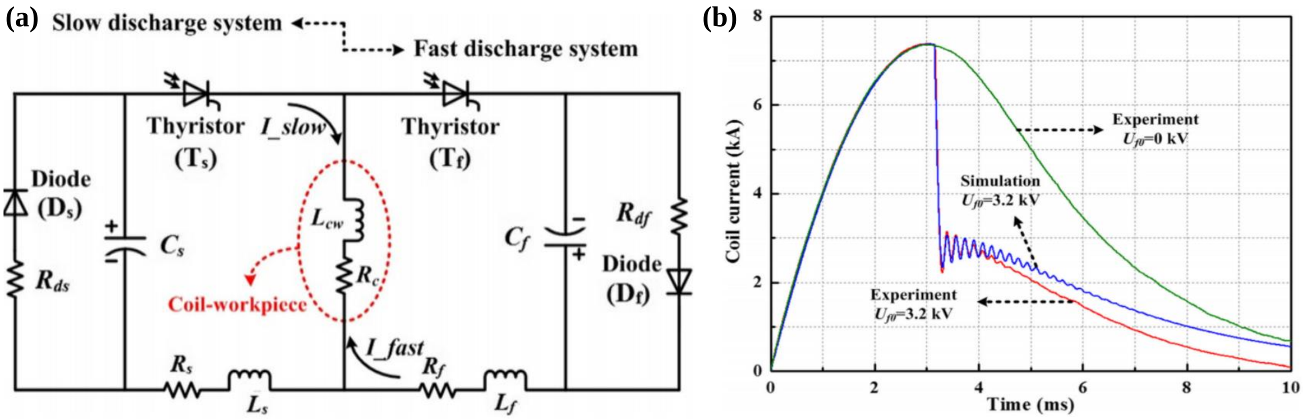

Fig. 5. (a) Schematic diagram of the electrical circuit of the EMF system for attractive forming process, (b) the proposed EMCE process; (b) experimentally measured discharge currents[11].

2.4 Electromagnetic Cold Expansion Process of Holes

Mechanical cold-expansion process has been widely used to improve the fatigue life of workpiece holes in aircrafts. However, there are some inherent and unavoidable features of this process such as contact way and non-uniform residual stress distribution, which restrict further improvement of the fatigue life of holes. To overcome these limitations, a novel electromagnetic cold expansion (EMCE) process with a dual-stage coil system is proposed in our previous work[12], which expands holes by a radial pulsed electromagnetic force. Figure 6(a) schematically shows the proposed EMCE system, in which the inner coils are responsible for producing toroidal currents in the workpiece and the the outer coils are used to produce an axial magnetic field in the region of workpiece. According to the Lorentz force equation, a toroidal current and an axial magnetic field can produce a radial electromagnetic force. The schematic diagram of the configurations and discharge timing of the two types of coils is shown in Fig. 6(b). Note that, the axial magnetic field generated by outer coils should have a long pulse width to avoid inducing eddy currents in the workpiece, and the directions of the axial magnetic field produced by the two types of coils should be opposite to generate an outward radial electromagnetic force acting on the workpiece. Meanwhile, the inner coils should discharge at the peak time of magnetic field generated by the outer coils to obtain a maximum radial electromagnetic force, as shown in Fig. 6(b). The effectiveness of the new EMCE process in improving fatigue life and fatigue limit of specimens has been verified by experimental tests for cold expansion of holes in sheets made of 2A12-T4 aluminum alloy. More details about the design principle, parameters of power supplies and coils as well as the expansion experiments can refer to our previous work[12].

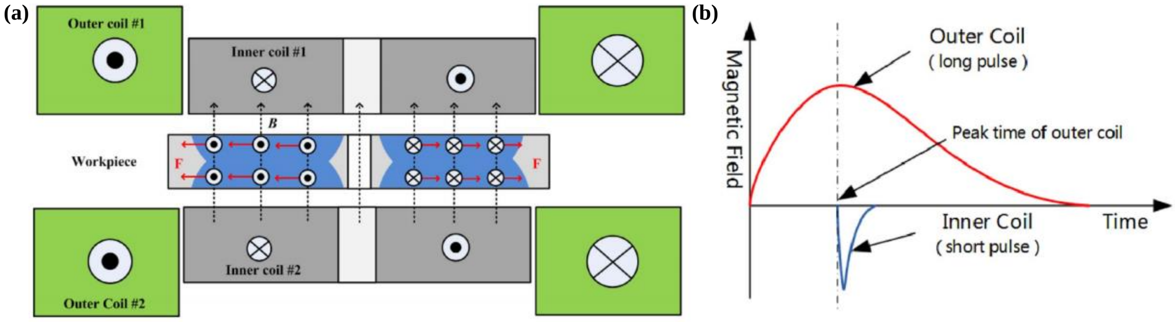

Fig. 6. (a) Schematic diagram of the proposed EMCE process; (b) schematic diagram of discharge timing of the inner and outer coils[12].

3. Conclusion

This paper summarizes the recent development of EMF process at WHMFC. Different with conventional EMF process with a single coil and a single power supply, the newly developed EMF processes at WHMFC can be seen as the category of Stic-Must-PMF forming technology that more than one coil or power supply are used. It has been clearly shown that, in comparison to conventional EMF, these Stic-Must-PMF forming processes have greater advantages and potential in forming large-scale and complex sheets. More studies for optimal control of multiple coils and power supplies according to different forming components will be carried out in the future to establish the rules of space-time control of multi-stage pulsed magnetic field and flexible electromagnetic force distribution in the forming process.

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