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Dependence on forming parameters of an integral panel during the electromagnetic incremental forming process

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Abstract Nowadays, more and more attentions are paid to electromagnetic incremental forming (EMIF), especially for a part with a large-scale size, e.g., an integral panel with stiffened ribs. In this work, the bending of a panel into a double-curvature profile via EMIF is carried out experimentally and evaluated by comparing the formed profile with the desired profile. During the process, discharges at four positions along different discharge paths are designed. The effects of forming parameters on the die-fittingness of the workpiece are discussed, for which two evaluation indices are used to judge forming results. The results show that a discharge voltage in an incremental mode is helpful to improve the fittingness and avoid the collision rebound against the die at the same time. Discharging at the diagonal positions with the "X" discharge path exhibits the minimal shape deviation and the best forming uniformity. On the contrary, discharging at the parallel positions with the "Z" discharge path obtains the worst forming quality. Overlap of the coil at different positions should be given during EMIF; however, a lower overlap rate of the coil helps improve the forming quality. The results obtained in this work are useful for forming integral panels with stiffened ribs via the EMIF process.

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1. Introduction

Integral panels, with high-stiffener having advantages of light weight, high stiffness, and high structural efficiency, have become important structural bearings and widely used in aircraft. However, because of their large sizes, net reinforced structures and structural stiffness, and requirements of good shape precision, the manufacture of integral panels has a high demand.[1] The conventional plastic forming methods for integral panels contain shot peen forming,[2] creep age forming,[3]

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press-bending,[4] roll forming, etc. Some successful examples and applications have been introduced in the "Integral Airframe Structures (IAS)" program.[5] However, due to the existence of stiffened ribs, there are many difficulties in processing compared to flat plate forming, and limitations can also be enumerated. Gariépy et al.[6] pointed out that for shot peen forming, the process needs complex designs mainly based on experience, and sometimes additional prestress is necessary. According to Zhan et al.,[7] creep age forming is limited to certain materials or occasions, and excessive time is spent in the process time including subsequent springback calibration. Since punch forces are applied directly on ribs, mentioned by Yan et al.,[8] instability and springback phenomena become the main problems during the brake forming process. In a word, the problems in the traditional forming methods of integral panels prompt researchers to explore novel forming technologies.

Electromagnetic forming (EMF) is an impulse or high-speed forming process using a pulsed magnetic field to apply Lorentz forces to workpieces preferably made of a highly electrically conductive material. Psyk et al.[9] reviewed that the formability limit can be increased and the production cycle can be shortened due to its high forming velocity. However, considering the large sizes of some parts, traditional EMF is difficult to apply directly because of the limited action scope and the depth of the magnetic field force from the coil with a fixed position. Therefore, some new methods have been proposed to overcome these difficulties. Kamal and Daehn[10] combined EMF and stamping via drawing to form a sheet with local features successfully. Lai et al.[11] utilized a large coil, of which the diameter is 860 mm, to form a large-scale sheet with a diameter of 1378 mm successfully. However, a large coil at a fixed position was still adopted, and it is difficult to form parts with complex structures directly.

In order to deal with the above challenges for large or complex parts, the idea of incremental forming was introduced by some researchers. Cui et al.[12] proposed an incremental forming method during EMF, called electromagnetic incremental forming (EMIF), to form large-scale sheets. In EMIF, a workpiece accumulates into the desired profile and fits well with the die gradually from one position to the adjacent via a small coil with small discharge energy moving and rotating along some certain paths in the space according to the requirement. In their study, comparing with traditional EMF, EMIF introduces some new forming parameters, such as discharge position, discharge pass, discharge path, coil overlap rate, etc., which result in complex coupling effects. Therefore, EMIF is a more complicated process than traditional EMF. At present, only a few researchers have conducted studies on EMIF. Zhao et al.[13] analyzed the forming uniformity under different coil overlap rates and different loading paths during the electromagnetic incremental bulging process of tubes. The results of their study showed that the higher the coil overlap rate, the better the forming uniformity, whereas the lower forming efficiency. Cui et al.[14] analyzed the effects of coil moving path, discharge pass, and other discharge parameters on electromagnetic incremental deep drawing of sheet metals. They reported that sheet components with good fittingness to the die were obtained by adopting reasonable process parameters. Xiong et al.[15] realized large-scale sheet forming via moving a coil along the axial direction. Tan et al.[16] investigated the EMIF process of several integral panels with different distributions of ribs. They established an FE model for the panels during the EMIF process, and discussed the distribution of electromagnetic force, the evolvement rule of velocity and height of the panels with different rib arrangements, as well as a comparison of forming quality between the panels obtained by brake forming and EMIF.

The characteristics of large sizes, high ribs, high structural rigidity, and complex and staggered high ribs grid structures of integral panels lead to that the effects of forming parameters in EMIF are different from those of pipes and metal sheets. Therefore, it is vital to study the influences of parameters in the EMIF process for designing an optimized forming scheme to obtain the ideal profile of an integral panel. This paper studies the effects of forming parameters, such as discharge parameters, geometric parameter, and discharge path on the die-fittingness of the workpiece to the die during EMIF, and the shape deviation and the forming uniformity are also evaluated.

2. Experimental arrangement

2.1. Experimental setup

The aim of utilizing EMIF in this study is to realize the bending of a semi-finished integrally stiffened panel (by milling on a plate to a thin web with several ribs) to the finial profile with double curvatures in two directions. The experimental installation for the integral panel is designed by Zhan et al.[17] and shown in Fig. 1. In order to facilitate the movement of the coil in the EMIF process, it is fixed between two support trays and bolted to a platen, where the platen is pressed by a hydraulic machine and can move horizontally on the blank holders to realize the incremental movement. The distance between the coil and the blank is adjusted through changing the height of the pads set between the platen and the coil. Fig. 2 shows the schematic of the forming process.

In this study, the material used in the EMIF experiments of the integral panels (Fig. 2) is 2A12-T4 aluminum alloy.[18] The web thickness and rib width of all the blanks are both 2 mm. A flat spiral coil is adopted, in which a copper wire, with a section area of 4 mm × 2 mm, is filled of resin with the roles of insulation and reinforcement. The wire is twined to three layers, and each layer has 10 winding turns wire. The inner radius is 7 mm and the gap between two adjacent layers is 0.4 mm. Two paths along the *X* and *Y* axes are defined to observe forming displacements, which will be discussed in Section 3. In the EMIF experiments, four discharge positions are designed, as shown in Fig. 2. A die with double curvatures is used in the EMIF process, as shown in Fig. 3.

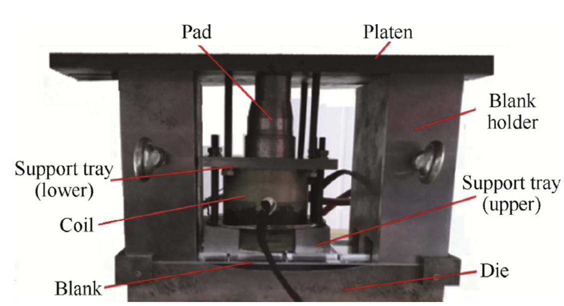

Fig. 1 Installation schematic diagram of EMIF.

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